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Pacific Environmental Services, Inc, Santa Monica, CA

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16. ABSTRACT

This document contains the text, as revised or originally written, of several sections prepared for inclusion in AP-42, "Compilation of Air Pollutant Emission Factors." Each section, or chapter of this document, includes: a description of the process, a process flow diagram, a characterization of the emissions, a discussion of applicable control options, and a quantification of the process's emissions, usually in the form of emission factors.

The source categories included herein are: solvent degreasing (or cleaning); transportation and marketing of petroleum liquids (gasoline trucks in transit); industrial surface coating including coil, can, wire, automobile, light-duty truck, large appliance, metal furniture, miscellaneous metal parts and products, flat wood interior panel, paper, and fabric coating; waste solvent reclamation; cleaning of rail tank cars, tank trucks, and drums; and asphaltic concrete plants (hot-mix asphalt). For each section, the background document which discusses the derivation and source of emission information is also included.

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FOR AP-42
ORGANIC SOURCE CATEGORIES

by

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INTRODUCTION

As the Table of Contents indicates, the chapters of this report were written for inclusion in EPA Publication No. AP-42, "Compilation of Air Pollutant Emission Factors." In February 1978, the following sections were assigned and were prepared in approximately the order listed:

4.4 Transportation and Marketing of Petroleum Liquids. The 4/77 version of this section was revised by PES to include "Transit Losses From Gasoline Tank Trucks;" the background document accompanying the revised text pertains only to the emission factors for such losses.

4.6 Solvent Degreasing.

4.2 Industrial Surface Coating.

In August 1978, three additional sections were assigned and written:

4.5 Waste Solvent Reclamation.

4.7 Tank and Drum Cleaning.

8.1 Asphaltic Concrete Plants. In December 1977, PES completed this section and a background document, for particulate emissions only, under a separate task assignment. In August 1978, the additions of organic emission factors and individual factor ratings were assigned under the present contract and task order. This assignment entailed partial revision of the text, tables, and the background document.

Five AP-42 sections were assigned that are not included herein:

5.23 Rubber Tire Manufacturing. A preliminary draft of this section and a partial background document were submitted to EPA in April 1978. The CTG document on "Rubber Products Manufacture" has since been postponed from July to December 1978, so revision and review of this section have also been delayed.

4.5 Graphic Arts. A preliminary draft of this section was started when the draft version of the CTG document on "Graphic Arts" was published. Since that time, the final publication date of this document has been postponed from July to December 1978, so completion of the AP-42 section also had to be postponed.

5.22 Adhesives. Publication of a CTG document on "Adhesives" has been postponed indefinitely, so this part of the original work assignment was canceled.

5.22 Explosives Detonation. A source document for this section was received in August 1978, along with the suggestion that its author be contacted for "other materials which he has access to and suggests using." PES agreed to read the source document and make requests for additional materials if so indicated, but suggested deferring preparation of the section due to the 5-week time limit involved. The Project Officer concurred.

5.22 Vinyl Chloride. An SSEIS document that deals with emissions of vinyl chloride from all kinds of sources was received, along with this section assignment, in August 1978. Because of the time limit involved and the fact that the source document includes no information on the conventional criteria pollutants, PES requested that preparation of this section be deferred. The Project Officer granted this request.

4.2 INDUSTRIAL SURFACE COATING

4.2.1 General [1-4]

4.2.1.1 Process Description - Surface coating involves the application of decorative or protective materials in liquid or powder form to any of a number of substrates. These coatings normally include general solvent-type paints, varnishes, lacquers, and water-thinned paints. After application by one of a variety of methods, such as brushing, rolling, spraying, dipping, and flow coating, the surface is air and/or oven dried to remove the volatile solvents leaving the coated surface. Powder type coatings can be applied to a hot surface or melted after application and caused to flow together. Other coatings can be applied normally, then polymerized by curing thermally with infrared or electron beam curing systems.

Coating Operations - There are both "toll" (also called "independent") and "captive" surface coating operations. Toll operations fill orders to various manufaturers' specifications, and thus change coatings and solvents more frequently than captive companies, which coat and fabricate products within a single facility and may operate continuously with the same solvents. Whether a surface coating operation is toll or captive makes a difference to what emission control systems are applicable to its coating lines because not all controls are technically feasible in toll situations.

Coating Formulations - Conventional coatings, which are still the most widely used, contain at least 30 volume percent solvents to permit easy handling and application. More typically, they contain 70 to 85 percent solvents by volume. These solvents may be of one component or a multicomponent mixture of volatile ethers, acetates, aromatics, cellosolves, aliphatic hydrocarbons, and/or water. Coatings with 30 volume percent of solvent or less are called low solvent (or "high solids") coatings.

Water-borne coatings, which have recently gained substantially in usage, are of several types: water emulsions, water soluble and colloidal dispersions, and electrocoats. Common ratios of water to organics in emulsion and dispersion coatings are 80/20 and 70/30.

Two part catalyzed coatings that can be dried, powder coatings, hot melts, and radiation cured (ultraviolet and electron beam) coatings contain essentially no volatile organic compounds (VOC), although some monomers and other lower molecular weight organics may volatilize.

Depending on the product requirements and material being coated a surface may have one or more layers of coating applied. The first coat may be applied to smooth out surface imperfections or to ensure adhesion of the coating. The intermediate coats usually provide the required color, texture, or print, and a final clear topcoat is often added as a protective measure. Although the intended use and material to be coated determines the composition and resins used in the coatings, the general coating types do not differ from those described.

Coating Application Procedures - Conventional spray, which is air-atomized and normally hand operated, is one of the most versatile coating methods. Colors can be changed easily and a variety of sizes and shapes can be painted under many operating conditions with good results. Conventional, catalyzed, and water-borne coatings can be applied with little modification. Disadvantages are low efficiency due to overspray and high energy requirements for the air compressor.

In hot, airless spray, the paint is forced through an atomizing nozzle under pressure. Since volumetric flow is less, overspray is reduced. Less solvent is also required, thus reducing VOC emissions. Care must be taken to avoid plugging and abrading of the nozzle orifice to ensure proper flow and atomization of the coating. Electrostatic spray is most efficient with low viscosity paints. Charged paint particles are attracted to an oppositely charged surface. Spray guns, spinning discs, or bell-shaped atomizers can be used to atomize the paint. Application efficiencies of 90 to 95 percent are possible with good wraparound and edge coating. Interiors and recessed surfaces are difficult to coat, however.

Roller coating is used to apply coatings and inks to flat surfaces. If the cylindrical rollers move in the same direction as the surface to be coated, the system is called a direct roll coater; if they rotate in the opposite direction, the system is a reverse roll coater. Coatings can be applied efficiently, uniformly, and at high speeds to any flat surface. Printing and decorative graining are applied with direct rollers. Reverse rollers are used to apply fillers to porous or imperfect substrates including papers, and fabrics, to give a smooth, uniform surface.

Knife coating is relatively inexpensive, but is not appropriate for coating unstable materials, such as some knitgoods, or when a high degree of accuracy in the coating thickness is required.

Rotogravure printing is widely used in vinyl coating of imitation leathers and wallpaper, and in the application of a transparent, protective pattern over the printed pattern. In rotogravure printing, the image area is recessed or "intaglio" relative to the copper-plated cylinder on which the image is engraved. The ink is picked up on the engraved area, and excess ink is scraped off the nonimage area with a "doctor blade." The image is transferred directly to the paper or other substrate, which is web fed; the product is then dried.

Dip coating requires that the surface to be coated be immersed into a bath of paint. Dipping is effective for coating irregular, bulky items and for priming. All surfaces are covered but coating thickness varies, edge blistering can occur, and a good appearance is not achieved.

In flow coating, materials to be coated are conveyed through a flow of paint. Paint flow is directed, without atomization, towards the surface through multiple nozzles, then caught in a trough and recycled. For flat surfaces, close control of film thickness can be maintained by passing the surface through a constantly flowing curtain of paint at a controlled rate.

4.2.1.2 Emissions and Controls - Essentially all of the volatile organic compounds (VOC) emitted from the surface coating industry result from the solvents which are either part of the paint formulations, used to thin paints at the coating facility, or used for cleanup. All unrecovered solvent can be considered as potential emissions. Monomers and low molecular weight organics can be emitted from those coatings that do not include solvents, but these emissions are essentially negligible.

Emissions from surface coating can be estimated for an uncontrolled facility by assuming that all VOC in the coatings are emitted as pollutants. Usually the coating consumption in gallons will be known and some information about the coating will be available. The factors in Table 4.2-1 can be used to calculate emissions. The choice of the particular factor will depend on the kind of coating data that is available. If no specific information is given for the coating, it may be estimated from the data in Table 4.2-2.

All solvents that are used in surface coating operations and not subsequently recovered can be considered as potential emissions.

Table 4.2-1. VOC EMISSION FACTORS FOR UNCONTROLLED SURFACE COATING (MATERIAL BALANCE WHEN VOLUME USAGE OF COATINGS IS KNOWN)

EMISSION FACTOR RATING: B

Available Information on Coating	Emissions of VOC[a]	
	kg/liter of coating	lb/gal of coating
Conventional or Water-borne Paints		
VOC as weight percent (d)	$\frac{d \cdot \text{coating density}}{100}$[b]	$\frac{d \cdot \text{coating density}}{100}$[b]
VOC as volume percent (V)	$\frac{V \cdot 0.88}{100}$	$\frac{V \cdot 7.36}{100}$
Water-Borne Paint		
VOC as weight percent of total volatiles - including water (X); total volatiles as weight percent of coating (d)	$\frac{d \cdot X \cdot \text{coating density}}{100}$[b]	$\frac{d \cdot X \cdot \text{coating density}}{100}$[b]
VOC as volume percent of total volatiles - including water (Y); total volatiles as volume percent of coating (V)	$\frac{V \cdot Y \cdot 0.88}{100}$	$\frac{V \cdot Y \cdot 7.36}{100}$

[a] For special purposes, factors expressed as lb/gal of coating less water may be desired. These may be computed as follows:

$$\frac{\text{Factor as lb/gal of coating}}{1 - \frac{\text{volume \% water}}{100}} = \text{Factor as lb/gal of coating less water}$$

[b] If the coating density is not known, it can be estimated from the information in Table 4.2-2.

Table 4.2-2. TYPICAL DENSITIES AND SOLIDS CONTENTS OF COATINGS[4]

Type of Coating	Density		Percent Solids (by volume)
	kg/liter	lb/gal	
Enamel, air dry	0.91	7.6	39.6
Enamel, baking	1.09	9.1	42.8
Acrylic enamel	1.07	8.9	30.3
Alkyd enamel	0.96	8.0	47.2
Primer surfacer	1.13	9.4	49.0
Primer, epoxy	1.26	10.5	57.2
Varnish, baking	0.79	6.6	35.3
Laquer, spraying	0.95	7.9	26.1
Vinyl, roller coat	0.92	7.7	12.0
Polyurethane	1.10	9.2	31.7
Stain	0.88	7.3	21.6
Sealer	0.84	7.0	11.7

Such VOC emissions at a facility can result from on-site dilution of coatings with solvent, from "make-up solvents" required in flow coating and in some instances in dip coating, and from the solvents used for cleanup. Make-up solvents are solvents that are added to coatings to compensate for standing losses in pressure, concentration, or amount, thus bringing the coating back to working specifications. Solvent emissions should be added to VOC emissions from coatings to arrive at total emissions from a coating facility.

Emission controls normally fall under one of three categories: modifications in paint formulations, process changes, or add-on controls. These are discussed more fully in the specific sections which follow. Typical ranges of control efficiencies are given in Table 4.2-3.

Table 4.2-3. EMISSIONS CONTROL EFFICIENCIES FOR SURFACE COATING OPERATIONS[1-3]

Control Option	Percentage Reduction[a]
Substitute water-borne coatings	60-95
Substitute low-solvent coatings	40-80
Substitute powder coatings	92-98
Add afterburners/incinerators	95

[a] Expressed in percentage of total uncontrolled emission load compared to that of a conventional solvent-borne coating.

4.2.2 Coil and Can Coating[5-8]

4.2.2.1 Process Description - Coil coating is the coating of any flat metal sheet or strip that comes in rolls or coils. Cans are made from two or three flat pieces of metal, so can coating is included within this broad category, which also includes the coating of screens, fencing, metal doors, aluminum siding, and a variety of other products. Figure 4.2-1 shows a typical coil coating line, while Figure 4.2-2 depicts a three-piece can sheet printing operation.

Coil Coating - There are both "toll" and "captive" coil coating operations. The former fill orders to customer specifications, while the latter coat the metal and fabricate the products within one facility. Some coil coaters serve both purposes.

Coil coating lines have one or more coaters, each followed by an oven (refer to Figure 4.2-1). The metal is cleaned and treated for corrosion protection and proper coating adhesion (refer to Section 4.6, Solvent Degreasing). The prime coat is applied, on one or both sides, by three or more power-driven rollers; it is typically reverse-roller coated. This coating is dried or baked, then cooled in a quench chamber either by a spray of water or by a blast of air followed by water cooling. Another method of applying a prime or single coat when a water-borne coating is used is electrodeposition.

Oven temperatures range from 40 to 380°C (100 to 1,000°F), depending on the type and desired thickness of the coating and on the type of metal being coated. A topcoat may be applied and cured in a similar manner.

Can Coating - As with coil coating, there are both toll and captive manufacturers. Some plants coat metal sheets, some fabricate three-piece cans, some fabricate and coat two-piece cans, and some fabricate can ends. Others perform combinations of these processes.

Cans may be either made from a rectangular sheet (body blank) and two circular ends ("three-piece" cans) or drawn and wall-ironed

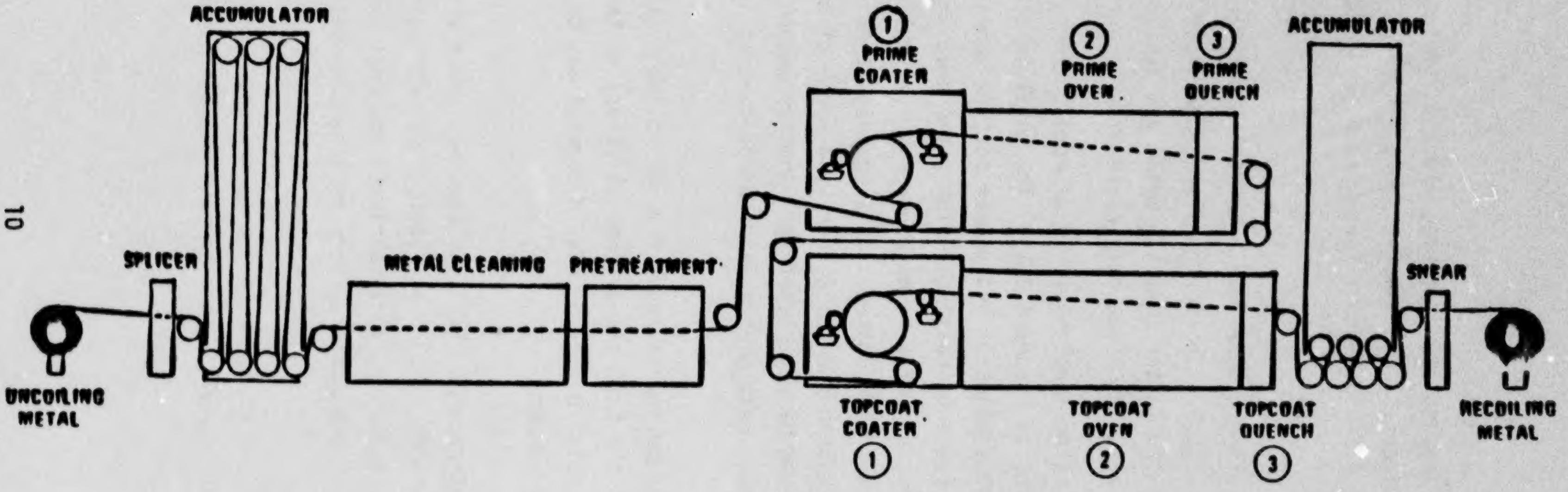

ACCUMULATOR
① PRIME COATER
② PRIME OVEN
③ PRIME QUENCH
ACCUMULATOR
SPLICER
METAL CLEANING
PRETREATMENT
SHEAR
UNCOILING METAL
TOPCOAT COATER ①
TOPCOAT OVEN ②
TOPCOAT QUENCH ③
RECOILING METAL

Figure 4.2-1 Coil Coating Line Emissions Points[7]

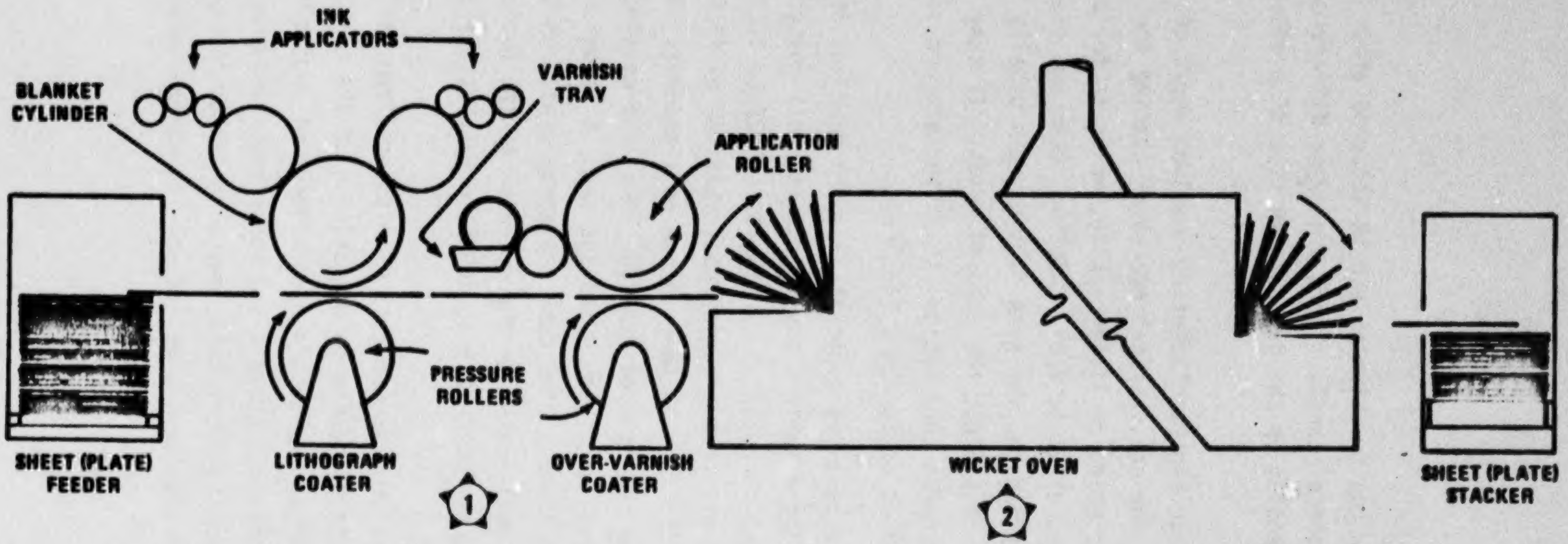

INK APPLICATORS
BLANKET CYLINDER
VARNISH TRAY
APPLICATION ROLLER
PRESSURE ROLLERS
SHEET (PLATE) FEEDER
LITHOGRAPH COATER
1
OVER-VARNISH COATER
WICKET OVEN
2
SHEET (PLATE) STACKER

Figure 4.2-2. Three-Piece Can Sheet Printing Operation Emission Points[7]

from a shallow cup to which an end is attached after the can is filled ("two-piece" cans). There are major differences in coating practices depending on the can and the type of product packaged in it.

Three-piece can manufacturing involves sheet coating (refer to Figure 4.2-2) and can fabricating; sheet coating includes base coating and printing or lithographing, which is followed by curing at temperatures of up to 220°C (425°F). When the sheets have been formed into cylinders, the seam is sprayed - usually with an air-dry lacquer - to protect the exposed metal. If they are to contain a product for human consumption, the interiors are spray coated and the cans baked at up to 220°C (425°F).

Two-piece cans are typically used by beer and other beverage industries. The exteriors may be reverse-roll coated with a white basecoat, which is cured at 170 to 200°C (325 to 400°F). Several colors of ink are then transferred (sometimes by lithographic printing) to the cans as they rotate on a mandrel. A protective varnish may be roll coated over the inks; the coating is then cured in a continuous, single or multipass oven at temperatures of 180 to 200°C (350 to 400°F). The cans are spray coated on the interior and spray and/or roll coated on the exterior of the bottom end. A final baking at 110 to 200°C (225 to 400°F) completes the process.

4.2.2.2 Emissions and Controls - Emissions from coil and can coating operations depend on composition of the coating, area to be coated, thickness of coat, and efficiency of application. Post-application chemical changes and nonsolvent contaminants, such as oven fuel combustion products, may also affect the composition of emissions. All solvent used and not recovered can be considered as potential emissions.

Coil Coating - Coil coating emissions come from (1) the coating area, (2) the oven, and (3) the quench area (these numbers refer to Figure 4.2-1). They consist of volatile organics and other compounds, such as aldehydes, which result from thermal degradation of volatile organics. Emissions from combustion of natural gas, which is typically used to heat the ovens, are discussed in Section 1.4. Emissions from coil coating can be estimated from the amount of coating applied by using the factors in Table 4.2-1.

Both incineration and the use of water-borne and low solvent coatings reduce organic vapor emissions; other technically feasible control options, such as electrostatically sprayed powder coatings, are not presently applicable to the industry as a whole. Both catalytic and thermal incinerators can be used, preferably with primary and/or secondary heat recovery systems. Water-borne primers, backers (coatings on the reverse or backside of the coil), and some low to medium gloss topcoats that equal the performance of organic solvent-borne coatings have been developed for aluminum, but have not yet achieved full line speed in all cases. Water-borne coatings for other metals are in the early stages of development.

Can Coating - Sources of can coating VOC emissions include (1) the coating area and (2) the oven area of the sheet base and lithographic coating lines (these numbers refer to Figure 4.2-2); the three-piece can side seam and interior body spray coating processes; and the two-piece can coating and end sealing compound lines. Emission rates vary depending on line speed, size of can or sheet, and type of coating. On sheet coating lines, where the coating is applied by rollers (refer to Figure 4.2-2), most solvent evaporates in the oven; for other coating processes, the coating operation itself is the major source of emissions. Emissions can be estimated from the amount of coating applied by using the factors in

Table 4.2-1, or from Table 4.2-4 if the number and general nature of the coating lines are known.

Available control technology includes the use of add-on devices (i.e., incinerators and carbon adsorbers) and the conversion to low solvent and ultraviolet curable coatings. Both thermal and catalytic incinerators may be used to control emissions from threepiece can sheet base coating lines, sheet lithographic coating lines, and interior spray coating; incineration is also applicable to two-piece can coating lines. Carbon adsorption, on the other hand, is most acceptable to low temperature processes which use a limited number of solvents. Such processes include two- and three- piece can interior spray coating, two-piece can end sealing compound lines, and three-piece can side seam spray coating.

Low solvent coatings are not yet available to replace all the organic solvent-borne formulations presently used in the can industry. Water-borne, low solvent, and powder coatings are in various stages of development. The requirement to gain approval by the Food and Drug Administration is a lengthy part of the testing program. Also, they cannot yet compete with conventional coatings in meeting customer specifications. Water-borne basecoats have been successfully applied to two-piece cans, however. Powder coating technology is being pursued for two-piece can interiors, and has been used for the side seam coating of noncemented three-piece cans.

Ultraviolet curing technology is available for rapid drying of the first two colors of ink on three-piece can sheet lithographic coating lines. It is still in the development stage for curing three-piece exterior basecoat, ink, and overvarnish in a single pass and for curing the exterior coating of two-piece beer and beverage cans.

Table 4.2-5 shows control efficiencies for typical, average coil and can coating lines.

Table 4.2-4 VOC EMISSION FACTORS FOR CAN COATING PROCESSES[7]

EMISSION FACTOR RATING: B

Process	Typical volatile organic emissions, from coating line[a]		Estimated fraction of emissions from coater area (percent)	Estimated fraction of emissions from oven (percent)	Typical organic emissions[b]	
	kg/hr	lb/hr			MT/yr	English ton/yr
Three-piece can sheet base coating line	51	112	9-12	88-91	176	160
Three-piece can sheet lithographic coating line	30	65	8-11	89-92	55	50
Three-piece beer and beverage can - side seam spray coating process	5	12	100	air dried	20	18
Three-piece beer and beverage can - interior body spray coating process	25	54	75-85	15-25	88	80
Two-piece can coating line	39	86	uncertain	uncertain	287	260
Two-piece can end sealing compound line	4	8	100	air-dried	15	14

[a] Organic solvent emissions will vary from line to line as a result of line speed, size of can or sheet being ocated, and type of coating used. A typical line may coat 500,000-200,000,000 cans per day or 100,000 sheets per day.

[b] Based upon normal operating conditions, which range from 1,500 to 7,000 hr/yr depending on the process.

Table 4.2-5. EMISSIONS CONTROL EFFICIENCIES FOR COIL AND CAN COATING LINES

Affected Facility[a]	Control Option	Percentage Reduction[b]
COIL COATING LINES	Thermal incineration	90-98
	Catalytic incineration	90
	Water-borne and high solids coatings	70-95
TWO-PIECE CAN LINES Exterior coating	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90
	Ultraviolet curing	up to 100
Interior spray coating	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90
	Powder coating	100
	Carbon adsorption	90
THREE-PIECE CAN LINES Sheet coating lines Exterior coating	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90
	Ultraviolet curing	up to 100
Interior spray coating	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90
Can fabricating lines		
Side seam spray coating	Water-borne and high solids coatings	60-90
	Powder (only for non-cemented seams)	100
Interior spray coating	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90
	Powder (only for non-cemented seams)	100
	Carbon adsorption	90
End coating lines Sealing compound	Water-borne and high solids coatings	70-95
Sheet coating	Carbon adsorption	90
	Thermal and catalytic incineration	90
	Water-borne and high solids coatings	60-90

[a] Coil coating lines consist of coaters, ovens, and quench areas. Sheet, can and end coating lines consist of coaters and ovens.

[b] Compared to conventional solvent-based coatings used without any add-On controls.

4.2.3 Magnet Wire Coating[9]

4.2.3.1 Process Description - Magnet wire coating is the process of applying a coating of electrically insulating varnish or enamel to aluminum or copper wire for use in electrical machinery. Wire is usually coated in large plants that both draw and insulate it; it is then sold to manufacturers of electrical equipment. The wire coating must meet rigid specifications of electrical, thermal, and abrasion resistance.

Figure 4.2-3 shows a typical wire coating operation. The wire is unwound from spools and passed through an annealing furnace. Annealing softens the wire and also cleans it by burning off oil and dirt. Typically, the wire then passes through a bath of coating at the coating applicator, and is subsequently drawn through an orifice or coating die that scrapes off the excess. It is then dried and cured in a two zone oven at about 200 and 430°C (400 and 806°F), respectively. Wire may pass through the coating applicator and the oven as many as 12 times in order to acquire the necessary thickness of coating.

4.2.3.2 Emissions and Controls - Emissions from wire coating operations depend on composition of the coating, thickness of coat, and efficiency of application. Postapplication chemical changes and nonsolvent contaminants, such as oven fuel combustion products, may also affect the composition of emissions.

The exhaust from the oven (1) is the most important source of solvent emissions in the wire coating plant. Emissions from the applicator (2) are low in comparison, primarily because a dip coating technique is used (these numbers refer to Figure 4.2-3). All solvent used and not recovered can be considered as potential emissions.

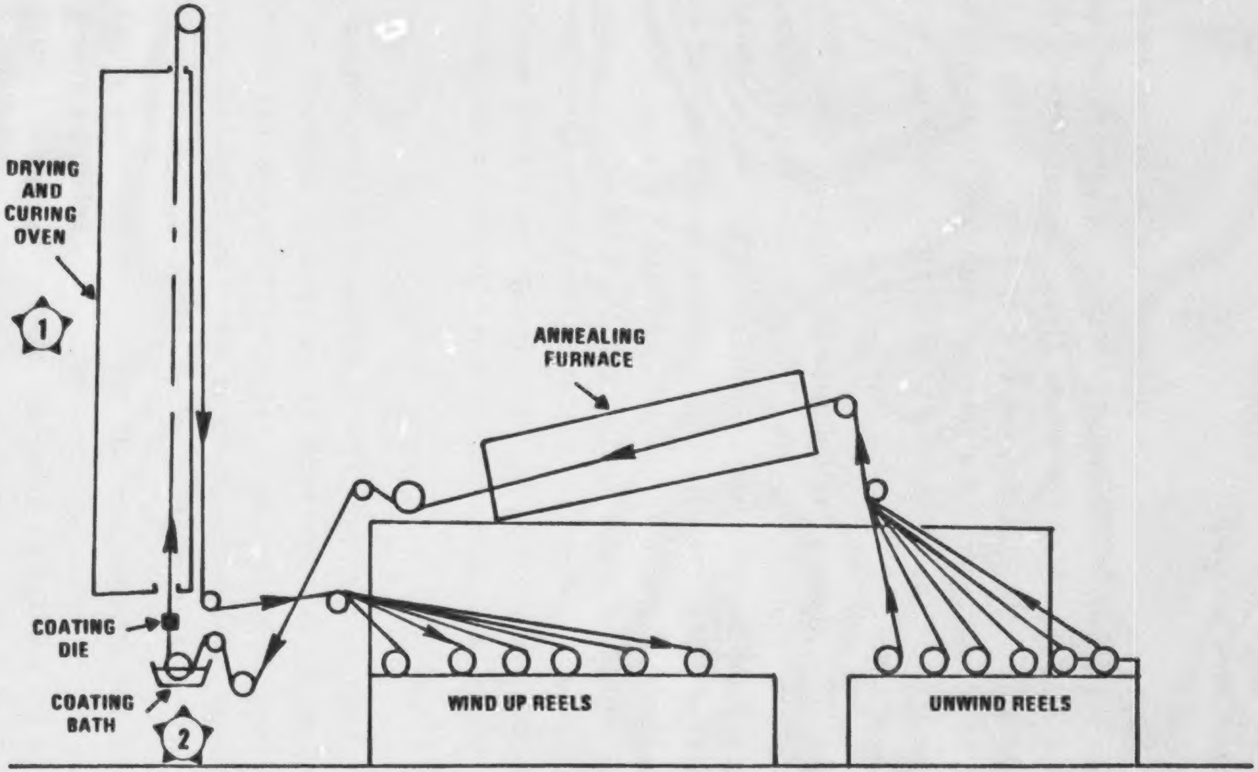

DRYING AND CURING OVEN
①
ANNEALING FURNACE
COATING DIE
COATING BATH
②
WIND UP REELS
UNWIND REELS

Figure 4.2-3. Wire Coating Line Emission Points[9]

VOC emissions may be estimated from the factors in Table 4.2-1 if the coating usage is known and it is known that the coater does not have any control. Since most wire coaters built since 1960 do have controls, the information in the following paragraph is probably applicable. Table 4.2-6 gives estimated emission factors for wire coating.

Incineration is the only control technique commonly used to control emissions from wire coating operations. Since about 1960, all major wire coating designers have incorporated catalytic incinerators into their oven designs because of the economic benefits. The internal catalytic incinerator burns solvent fumes and recirculates the heat back into the wire drying zone. Fuel otherwise needed to operate the oven is eliminated or greatly reduced, thus resulting in cost savings. Essentially all solvent emissions from the oven can be directed to an incinerator with a combustion efficiency of at least 90 percent.

Ultraviolet-cured coatings are available for specialized systems. Carbon adsorption is not practical for several reasons. Low solvent coatings are only a potential control because they have not yet been developed with the properties that will meet all the industry's needs.

4.2.4 Automobile and Light-Duty Truck Coating

4.2.4.1 Process Description[7] - Automobile (passenger vehicles seating 12 or fewer people) and light-duty truck (8,500 lb gross vehicle weight or less) assembly lines usually produce from 30 to 65 units per hour. The assembly industry receives parts from a variety of sources and produces finished vehicles for dealers, assembling one general body style in various models on each line.

Table 4.2-6. ORGANIC SOLVENT EMISSIONS FROM A TYPICAL WIRE COATING LINE[9]

EMISSION FACTOR RATING: B

Typical volatile organic emissions from coating line[a]		Typical annual organic emissions[b]	
kg/hr	lb/hr	MT/yr	English ton/yr
12	26	102	93

[a] Organic solvent emissions vary from line to line as a result of size and speed of the wire, number of wires per oven, and the number of passes through the oven. A typical line may coat 1,200 pounds of wire per day.

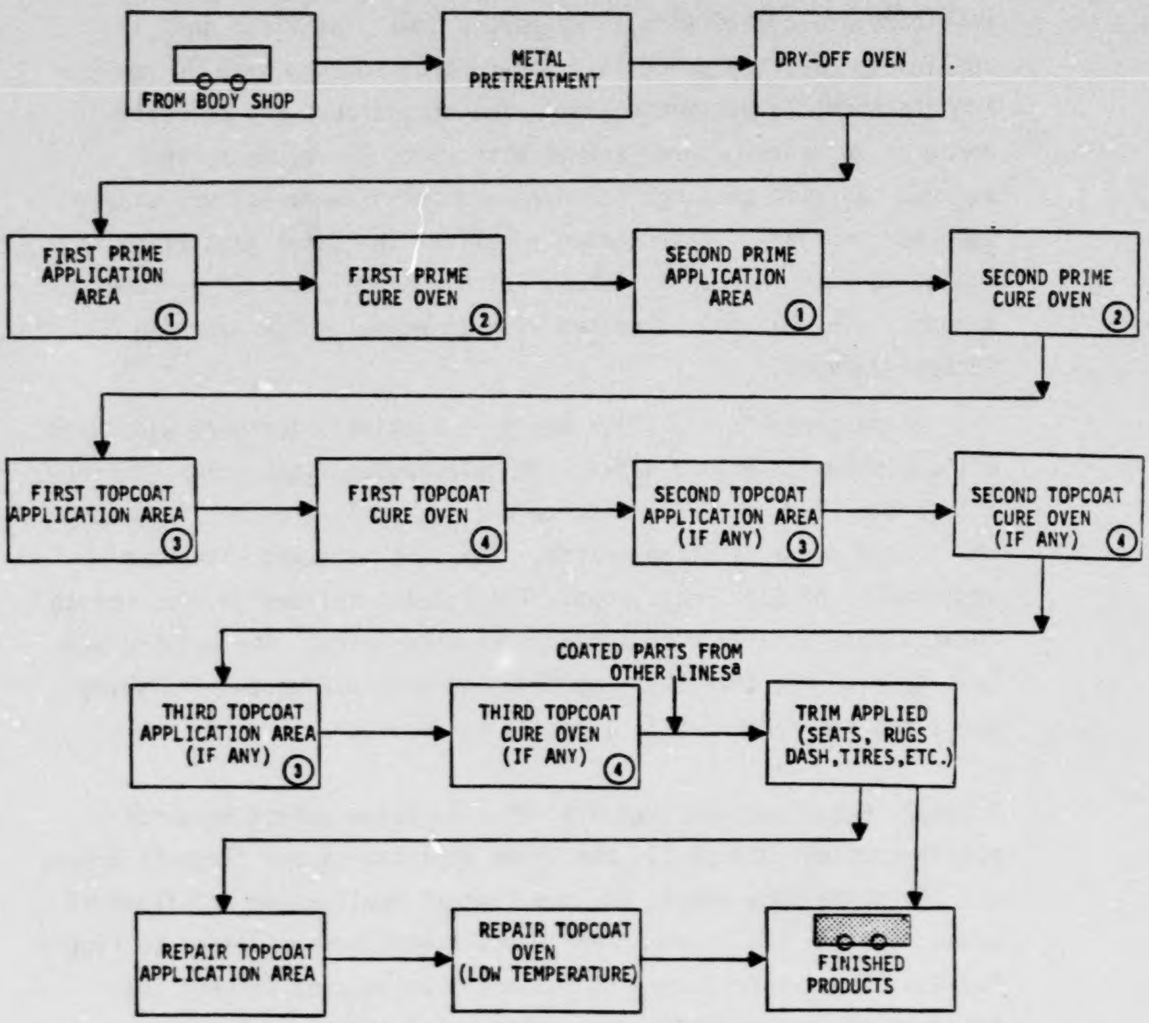
[b] Based upon normal operating conditions of 7,000 hr/yr.

Lacquers and enamels are both used in automobile coating. Most cars are coated with a two part prime. The first coat is applied by electrodipping in a water-borne coating that is equivalent to about 75 percent solids. The second coat may be water-borne or an organic-borne enamel with 25 to 35 volume percent solids. Acrylic coatings (either lacquers or enamels) are widely used for topcoats. Approximately half of the total production is topcoated with lacquer finishes, which average about 88 percent solvent. The balance is coated with an enamel which averages 68 percent solvent.

Although no "typical" assembly line exists, features common to all are shown in Figure 4.2-4. The electrodeposited prime coat requires two steps; the first prime coat is applied by dipping, while the second prime is spray coated. The unit is baked after the application of each prime coat. The topcoat follows in from one to three steps, usually with a bake step after each. The painted body then goes to the trim shop; coatings damaged during the finishing operation are repainted in a repair spray booth.

4.2.4.2 Emissions and Controls[7,10] - Emission points in automobile coating include (1) the prime application and flashoff areas, (2) the prime cure ovens, (3) the topcoat application and flashoff areas, and (4) the topcoat cure ovens (these numbers refer to Figure 4.2-4). The flashoff area is the evaporation area between the application area and the oven. When using organic solvent-borne spray, 85 to 90 percent evaporates in the booth and flashoff areas, and the remaining 10 to 15 percent evaporates in the ovens.

Uncontrolled emissions vary greatly depending on vehicle size, line speed, coating thickness, and, most importantly, the solvent content and composition of the coatings. The amount of organic solvent emitted per vehicle for several coating categories is shown


FROM BODY SHOP
METAL PRETREATMENT
DRY-OFF OVEN
FIRST PRIME APPLICATION AREA ①
FIRST PRIME CURE OVEN ②
SECOND PRIME APPLICATION AREA ①
SECOND PRIME CURE OVEN ②
FIRST TOPCOAT APPLICATION AREA ③
FIRST TOPCOAT CURE OVEN ④
SECOND TOPCOAT APPLICATION AREA (IF ANY) ③
SECOND TOPCOAT CURE OVEN (IF ANY) ④
THIRD TOPCOAT APPLICATION AREA (IF ANY) ③
THIRD TOPCOAT CURE OVEN (IF ANY) ④
COATED PARTS FROM OTHER LINES[a]
TRIM APPLIED (SEATS, RUGS DASH,TIRES,ETC.)
REPAIR TOPCOAT APPLICATION AREA
REPAIR TOPCOAT OVEN (LOW TEMPERATURE)
FINISHED PRODUCTS

[a] Main bodies may be on separate lines from hoods and fenders

Figure 4.2-4. Automobile and Light-Duty Truck Coating Line Emission Points[7]

in Table 4.2-7. If total coating usage is known, uncontrolled emissions can be estimated using the factors from Table 4.2-1. All solvent used and not recovered can be considered as potential emissions.

Emissions from most prime application systems have been reduced by converting to an electrodeposited water-borne prime. Other control options for those plants that still prime with organic-borne coatings include spraying or dipping with a water-borne surfacer (also called a guidecoat) and using a higher solids (less than 50 volume percent solvent) prime. Incineration and carbon adsorption may also reduce emissions from solvent-borne primes. Emissions from the prime cure oven are reduced by using water-borne electrodeposition, low solvent primes, or incineration.

About 66 percent of uncontrolled emissions from automobile coating lines come from the topcoat application areas. Powder coatings generally have not been employed in the U.S. because of the difficulty of changing colors and because metallic coatings cannot yet be applied satisfactorily by this method. Incineration and carbon adsorption of spray booth exhaust are technically feasible, and major auto firms are now evaluating these add-on devices for spray booths. Thus, control options for this major emission point are currently limited to water-borne or low solvent topcoats. Topcoat cure oven emissions can be reduced by conversion to water-borne or low solvent coatings and by incineration of oven exhaust.

Table 4.2-8 gives control efficiencies for auto coating lines.

4.2.5 Other Metal Coating[11-13]

4.2.5.1 Process Description - Large appliance, metal furniture, and miscellaneous part and product coating lines have most

Table 4.2-7. EMISSIONS FACTORS FOR A TYPICAL PLANT ASSEMBLING INTERMEDIATE-SIZED AUTOMOBILES AND LIGHT-DUTY TRUCKS[7]

EMISSION FACTOR RATING: B

Coating Type (percent solids by volume)	Prime Application				Prime Oven				Topcoat Application				Topcoat Oven			
	Solvent Exhaust Rate		Solvent Emissions		Solvent Exhaust Rate		Solvent Emissions		Solvent Exhaust Rate		Solvent Emissions		Solvent Exhaust Rate		Solvent Emissions	
	kg/hr	lb/hr	kg/car	lb/car	kg/hr	lb/hr	kg/car	lb/car	kg/hr	lb/hr	kg/hr	lb/car	kg/hr	lb/hr	kg/car	lb/car
12% Solution Lacquer	b	b	b	b	b	b	b	b	1,129	2,490	18.8	41.5	199	438	3.3	7.3
18% Dispersion Lacquer	b	b	b	b	b	b	b	b	701	1,546	11.7	25.8	96	212	1.6	3.5
32% Enamel	163	360	2.7	6.0	29	64	0.5	1.1	327	720	5.4	12.0	58	127	0.9	2.1
50% Enamel	77	170	1.3	2.8	13.6	30	0.2	0.5	154	340	2.6	5.7	27.2	60	0.5	1.0
Water-Borne	negligible	negligible	small	small	18.1	40	0.3	0.7	38.5	85	0.6	1.4	38.5	85	0.6	1.4

[a] From Reference 7. Assumptions: Rate of assembly of 60 vehicles per hour. Solvent corresponds to 50-50 mole percent Hexane-Benzene; 85 percent of emissions are in Application Area(s) for Solvent-Borne Coatings; 50 percent of emissions are in Application Area(s) for Water-Borne Topcoat; 30 gal/hr of Solids are applied for Prime Coat; 60 gal/hr of Solids are applied for Topcoat; Application Area Exhaust at 100 ppm was 0.0228 lb/10^3 scf; Oven Exhaust at 10 percent of LEL was 0.296 lb/10^3 scf; Organic Solvent Density was 6.665 lb/gal. For Water-Borne, percent of LEL was lower.

[b] Not applicable.

Table 4.2-8. CONTROL EFFICIENCIES FOR AUTOMOBILE AND LIGHT-DUTY TRUCK COATING LINES[7]

Affected Facility[a]	Control Option	Percentage Reduction
Prime application[b] and flashoff area	Water-borne (electro-deposition)[c]	80[d] -93[e]
	50 volume percent solids prime	0[d] -65[e]
	Incineration	90+
	Carbon adsorption	85+
Prime cure oven	Water-borne (electro-deposition)[c]	80[d] -93[e]
	>50 volume percent solids prime	0[d] -65[e]
	Incineration	90+
Topcoat application and flashoff area[b]	Water-borne topcoat[c]	40[d,g] -92[f,g]
	>50 volume percent solids topcoat	0[d] -86[f]
	Incineration	90+
	Carbon adsorption	85+
Topcoat cure oven	Water-borne topcoat[c]	40[d,g] -92[f,g]
	>50 volume percent solids topcoat	0[f] -86[f]
	Incineration	90+

[a] These control options are applicable to all assembly and subassembly lines in the plant, including those for frames, small parts, wheels, and main body parts.

[b] The application areas are the areas where the coating is applied by dip or spray. The flashoff area is the space between the application area and the oven.

[c] These options reduce emissions from application, flashoff and cure. The percentage reduction given is the reduction from all of these sources.

[d] Based on an original coating with 50 volume percent solids (3.7 lbs/gal less water).

[e] Based on an original coating with 26 volume percent solids (5.5 lbs/gal less water). Water-borne surfacer (guidecoat) is included.

[f] Based on an original coating with 12 volume percent solids (6.5 lbs/gal less water).

[g] Based on a water-borne topcoat with 2.76 pounds of organic solvent per gallon of coating minus water (e.g., 25 volume percent solids, 15 volume percent organic solvent and 60 volume percent water).

steps in common; these processes also have similar emissions, emission points, and available control technology. Figure 4.2-5 shows a typical metal furniture coating line.

Large appliances include doors, cases, lids, panels, and interior support parts of washers, dryers, ranges, refrigerators, freezers, water heaters, air conditioners, and other associated products. Metal furniture includes both outdoor and indoor pieces manufactured for household and for business and institutional use. "Miscellaneous parts and products" herein denotes large and small farm machinery, small appliances, commercial and industrial machinery, fabricated metal products, and other industrial categories that coat metal under Standard Industrial Classification (SIC) codes 33 to 41.

Large Appliances - The coatings typically applied to large appliances are epoxy, epoxy-acrylic, or polyester enamels for the primer or single coat, and acrylic enamel for the topcoat; coatings containing alkyd resins are also used in some cases. Prime and interior single coats are applied at about 25 to 36 volume percent solids; topcoats and exterior single coats are applied 30 to 40 volume percent. Lacquers may be used to touch up any scratches that occur during assembly. Coatings contain 2 to 15 solvents; typical solvents used are esters, ketones, aliphatics, alcohols, aromatics, ethers, and terpenes.

Small parts are typically dip coated, while flow or spray coating is used for larger parts. Dip and flow coating are either performed in an enclosed room vented by a roof fan or emissions are vented by an exhaust system adjoining the drain board or tunnel. Down- or side-draft booths remove overspray and organic vapors from prime coat spraying. Spray booths are also equipped with dry filters or a water wash to trap overspray.

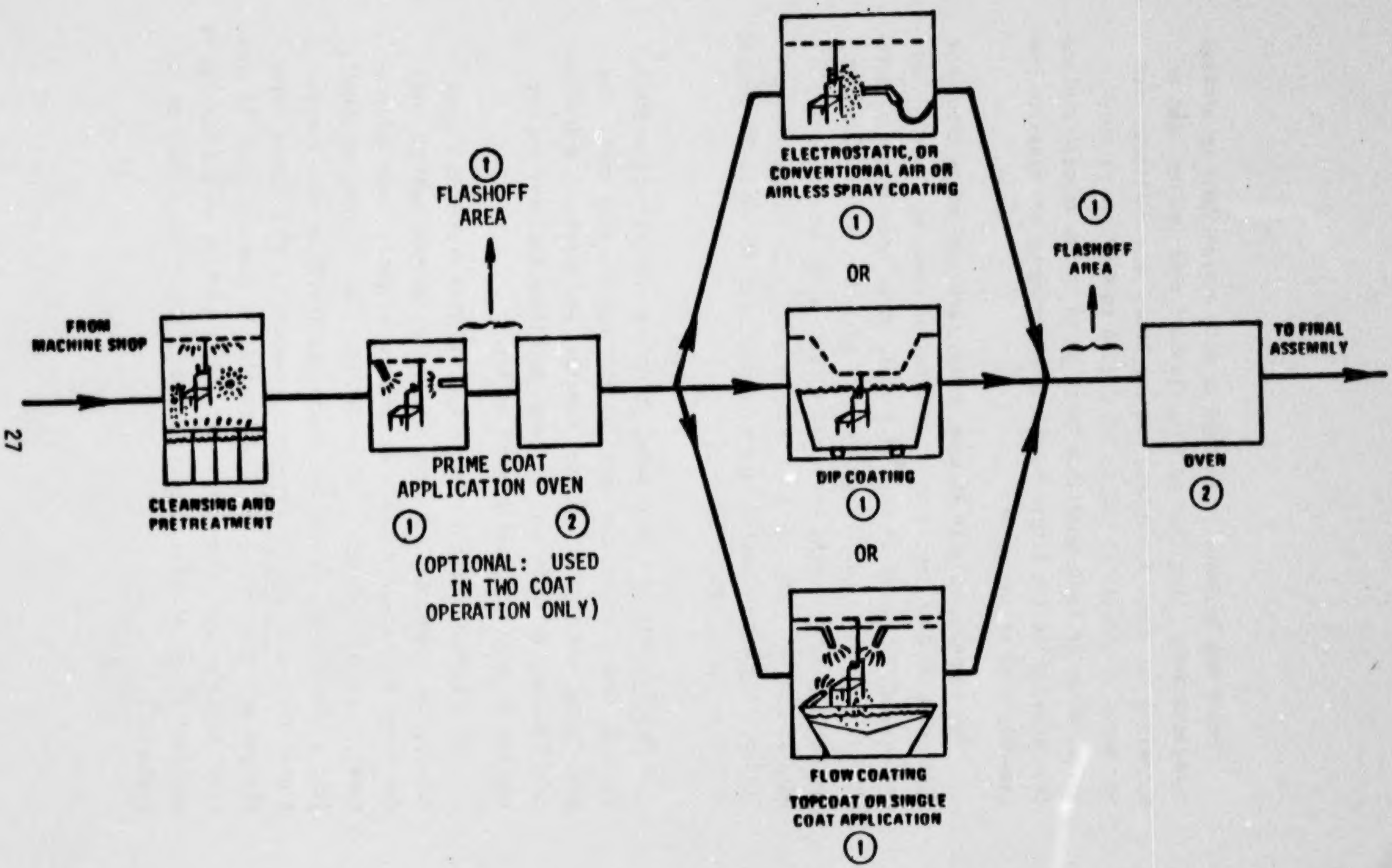

FROM MACHINE SHOP
CLEANSING AND PRETREATMENT
① FLASHOFF AREA
PRIME COAT APPLICATION ①
OVEN ②
(OPTIONAL: USED IN TWO COAT OPERATION ONLY)
ELECTROSTATIC, OR CONVENTIONAL AIR OR AIRLESS SPRAY COATING ①
OR
DIP COATING ①
OR
FLOW COATING
TOPCOAT OR SINGLE COAT APPLICATION ①
① FLASHOFF AREA
OVEN ②
TO FINAL ASSEMBLY

Figure 4.2-5. Metal Product Coating Line Emission Points[11]

Parts may be manually touched up with conventional or airless spray equipment; they then go to a flashoff area (either open or tunneled) for about 7 minutes, and are baked in a multipass oven for about 20 minutes at 180 to 230°C (350 to 450°F). At this point, exterior large appliance parts go on to the topcoat application area, while the single coated interior parts are moved to the assembly area of the plant.

The topcoat, as well as some primes, are applied by automated electrostatic disc, bell, or other types of spray equipment. Topcoats usually consist of several colors, which are changed by automatically flushing out the system with solvent. Both the topcoat and touchup spray booths are designed with side- or down-draft exhaust control. The parts go through about a 10 minute flashoff period, followed by baking in a multipass oven for 20 to 30 minutes at 140 to 180°C (270 to 350°F).

Metal Furniture - Most metal furniture coatings are enamels, although some lacquers and metallic coatings are also used. The most common coatings are alkyds, epoxies, and acrylics, which contain the same solvents used in large appliance coatings and are applied at about 25 to 35 percent solids.

On a typical metal furniture coating line (refer to Figure 4.2-5), the prime coat can be applied with the same methods used for large appliances, but may be cured at slightly lower temperatures, i.e., 160 to 200°C (300 to 400°F). The topcoat, or usually just a single coat, is applied electrostatically or with conventional airless or air spray methods, especially if frequent color changes are required. Most spray coating is done manually, in contrast to large appliance operations. Flow coating or dip coating is employed if the plant generally uses only one or two colors on its products.

The coated furniture is usually baked, but in some cases it is air dried. If the furniture is to be baked, it passes through a flashoff area into a multizone oven at temperatures ranging from 160 to 230°C (300 to 450°F).

Miscellaneous Metal Parts and Products - Both enamels (30 to 40 volume percent solids) and lacquers (10 to 20 volume percent solids) are used to coat miscellaneous metal parts and products, although enamels are more commonly used. Coatings are often purchased at higher volume percent solids but thinned prior to application (frequently with aromatic blends). Alkyds are popular among industrial and farm machinery manufacturers. Most of the coatings contain several (up to 10) different solvents, including ketones, esters, alcohols, aliphatics, ethers, aromatics, and terpenes.

Coatings are applied in both conveyorized and batch, single and two coat operations. Spraying is usually employed for single coats, but flow and dip coating may be used when only one or two colors are applied. For two coat operations, primers are typically applied by flow or dip coating, while topcoats are almost always applied by spraying. Electrostatic spraying is common. Spray booths are maintained at a slight negative pressure to capture overspray.

A manual two coat operation may be used for large items, such as industrial and farm machinery. The coatings on such products are air dried rather than oven baked because the machinery, which is completely assembled, includes heat sensitive materials and may be too large to be cured in an oven. However, smaller miscellaneous parts and products are baked in single or multipass ovens at 150 to 230°C (275 to 450°F).

4.2.5.2 Emissions and Controls - Volatile organic compounds (VOC) are emitted from (1) the application and flashoff areas and

(2) the ovens of metal coating lines (these numbers refer to Figure 4.2-5). The composition of emissions varies among coating lines according to construction, coating method, and type of coating applied, but the distribution of emissions among individual operations is fairly constant regardless of the specific product coated, as Table 4.2-9 indicates. All solvent used and not recovered can be considered to be potential emissions. Emissions can be calculated from the factors in Table 4.2-1 if coatings usage is known, or from the factors in Table 4.2-9 if only a general description of the plant is available. For emissions from the cleansing and pretreatment area, see Section 4.6, Solvent Degreasing.

Table 4.2-9. EMISSION FACTORS FOR TYPICAL UNCONTROLLED METAL COATING PLANTS[11-13]

EMISSION FACTOR RATING: B

Type of Plant	Production Rate	Emissions		Estimated Percentage of Emissions From	
		MT/yr	English ton/yr	Application and Flashoff	Ovens
Large Appliances -					
Prime and topcoats, spray	768,000 units/yr	630	571	80	20
Metal Furniture -					
Single spray coat	48×10^6 ft^2/yr	355	322	65 - 80	20 - 35
Single dip coat	23×10^6 ft^2/yr	140	127	50 - 60	40 - 50
Miscellaneous Metal -					
Conveyorized single flow coat	16×10^6 ft^2/yr	86	78	50 - 60	40 - 50
Conveyorized single dip-coat	16×10^6 ft^2/yr	86	78	40 - 50	50 - 60
Conveyorized single spray-coat	16×10^6 ft^2/yr	103	93	70 - 80	20 - 30
Conveyorized two-coat, flow and spray	16×10^6 ft^2/yr	190	172	60 - 70	30 - 40
Conveyorized two-coat, dip and spray	16×10^6 ft^2/yr	190	172	60 - 70	30 - 40
Conveyorized two-coat, spray	16×10^6 ft^2/yr	206	187	70 - 80	20 - 30
Manual two-coat, spray and air dry	8.5×10^6 ft^2/yr	30	27	100	0

Powder coatings, which contain almost no VOC, can be applied to some metal products as a modification in coating formulation to reduce emissions. Powder coatings are applied as single coats on some interior large appliance parts and as topcoats for ranges;

they are also used on metal bed and chair frames, shelving, and stadium seating, and have been applied as single coats on small appliances, small farm machinery, fabricated metal product parts, and industrial machinery component parts. The usual application method is manual or automatic electrostatic spraying.

An additional control consists of electrostatic coating of metal products. Many large appliance manufacturers are now using electrodeposition to apply the prime coat to exterior parts and the single coat to interior parts because this technique increases corrosion protection and detergent resistance. Electrodeposition of water-borne coatings is also being used at several metal furniture coating plants and at some farm and commercial machinery and fabricated metal product facilities. Water-borne coatings may be applied with conventional spray, dip, and flow coating equipment as well.

Low solvent coatings (45 to 50 volume percent solids) are being applied as topcoats on some refrigerators, thereby reducing solvent input and thus VOC emissions. Automated electrostatic spraying is most efficient, but manual and conventional techniques can also be used. Roll coating is another option on some miscellaneous parts.

Carbon adsorption is technically feasible for collecting emissions from the prime, top, and single coat application and flashoff areas, but there are no known installations to date on metal coating lines.

Incineration has been used to reduce organic vapor emissions from large appliance, metal furniture, and miscellaneous product baking ovens. If sufficient heat recovery can be used to reduce fuel consumption, incinerators are also an option for controlling application and flashoff area emissions.

Additional control techniques include trapping overspray by means of dry filters or a water wash in the spray booths and enclosing flashoff areas. Air inlet velocities required to prevent effluent from spilling into the work areas from such openings can be minimized by using air curtains at these openings.

Table 4.2-10 gives estimated control efficiencies for large appliance, metal furniture, and miscellaneous metal part and product coating lines.

Table 4.2-10. ESTIMATED CONTROL TECHNOLOGY EFFICIENCIES FOR METAL COATING LINES[a]

Control Technology	Application			Reduction in Organic Emissions (percent)		
	Large Appliances	Metal Furniture	Miscellaneous	Large Appliances	Metal Furniture	Miscellaneous
Powder	Top, exterior, or interior single coat	Top or single coat	Oven baked single coat or topcoat	95-99[b]	95-99[b]	95-98[d]
Water-borne (spray, dip, or flowcoat)	All applications	Prime, top, or single coat	Oven baked single coat, primer, and topcoat; air dried primer and topcoat	70-90[b]	60-90[b]	60-90[d]
Water-borne (electrodeposition)	Prime or interior single coat	Prime or single coat	Oven baked single coat and primer	90-95[b]	90-95[b]	90-95[d]
Higher solids (spray)	Top or exterior single coat and sound deadener	Top or single coat	Oven baked single coat and topcoat; air dried primer and topcoat	60-80[b]	50-80[b]	50-80[d]
Carbon adsorption	Prime, single, or topcoat application and flashoff areas	Prime, top, or single coat application and flashoff areas	Oven baked single coat, primer, and topcoat application and flashoff areas; air dried primer and topcoat application and drying areas	90[c]	90[c]	90[c]
Incineration	Prime, top, or single coat ovens	Ovens	Ovens	90[c]	90[c]	90+[c]

[a] From References 11-13.

[b] The base case against which these percent reductions were calcualted is a high organic solvent coating which contains 25 volume percent solids and 75 volume percent organic solvents. The transfer efficiencies for liquid coatings were assumed to be about 80 percent for spray and 90 percent for dip or flowcoat, for powders about 93 percent, and for electrodeposition 99 percent.

[c] This percent reduction in VOC emissions is only across the control device, and does not take into account the capture efficiency.

[d] These figures reflect only the range in reduction possible. The actual reduction achieved depends on the compositions of the conventional coating originally used and the replacement low organic solvent coating, on transfer efficiency, and on the relative film thicknesses of the two coatings.

4.2.6 Flat Wood Interior Panel Coating

4.2.6.1 Process Description[14] - Prefinished flat wood construction products included in this subcategory of industrial surface coating are interior panelings made of hardwood plywood (natural and lauan), particleboard, and hardboard.

Less than 25 percent of the manufacturers of such flat wood products coat the products in their plants, and in some of the plants that do coat, only a small percentage of the total production capacity is coated. At present, most coating is done by toll coaters who receive panels from manufacturers and prefinish or finish them according to customer specifications and product requirements.

Some of the layers in any given species of coatings that can be factory applied to flat woods are filler, sealer, groove coat, primer, stain, basecoat, inks, and topcoat. The solvents used in organic-based flat wood coatings are normally multicomponent mixtures, including methyl ethyl ketone, methyl isobutyl ketone, toluene, xylene, butyl acetates, propanol, ethanol, butanol, VM&P naphtha, methanol, amyl acetate, mineral spirits, SoCal I and II, glycols, and glycol ethers. Those most often used in water-borne coatings are glycol, glycol ethers, propanol, and butanol.

Different forms of roll coating are the preferred techniques for applying coatings to flat woods. Coatings used for surface coverage can be applied with a direct roller coater, while reverse roll coaters are generally used to apply fillers in order to force the filler into panel cracks and voids. Precision coating and printing (usually with offset gravure grain printers) are also forms of roll coating, and several types of curtain coating may be employed as well (usually for application of the topcoat). Various spray techniques and brush coating may be utilized, too.

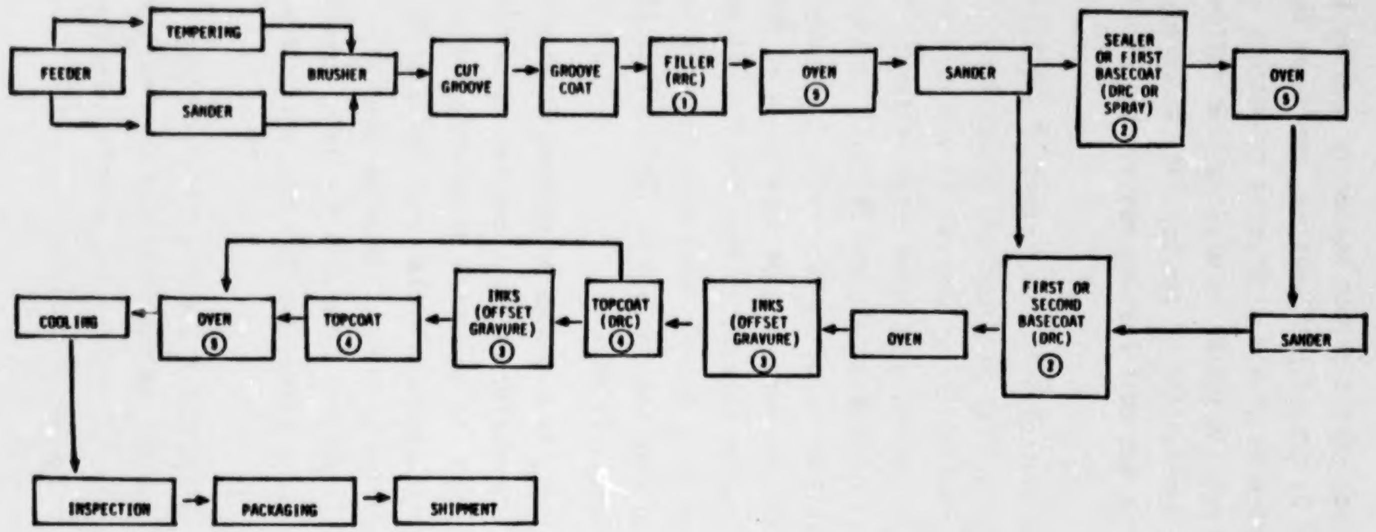
Printed interior panelings are produced from plywoods with hardwood surfaces (primarily lauan) and from various wood composition panels, including hardboard and particleboard. Finishing techniques are used primarily to cover the original surface; they also serve to produce various decorative effects. Figure 4.2-6 is a general flow diagram showing some but not all typical production line variations for printed interior paneling.

Groove coatings, which can be applied in different ways and at different points in the coating procedure, are usually pigmented, low resin solids that are reduced with water prior to use and so yield few if any emissions. Fillers, which are normally applied by reverse roll coating, may be of various formulations: (1) polyester (which is ultraviolet cured), (2) water-based, (3) lacquer-based, (4) polyurethane, and (5) alkyd urea-based. Water-based fillers are in common use on printed paneling lines.

Sealers may be water- or solvent-based, and are usually applied by airless spray or direct roll coating, respectively. Basecoats, which are usually direct roll coated, generally fall into the following categories: lacquer, synthetic, vinyl, modified alkyd urea, catalyzed vinyl, and water-based (which are now used at some lauan finishing plants).

Inks are applied by an offset gravure printing operation similar to direct roll coating. Most lauan printing inks are pigments dispersed in alkyd resin with some nitrocellulose added for better wipe and printability. Water-based inks have a good future for clarity, cost, and ecological reasons. After printing, the board goes through one or two direct or precision roll coaters for application of the clear, protective topcoat. Some topcoats are synthetic, prepared from solvent soluble alkyd or polyester resins, urea formaldehyde cross linkings, resins, and solvents.

Natural hardwood plywood panels are coated with transparent or clear finishes to enhance and protect their face ply of hardwood veneer. Typical production lines are similar to those for printed


FEEDER
TEMPERING
SANDER
BRUSHER
CUT GROOVE
GROOVE COAT
FILLER (RRC) ①
OVEN ⑤
SANDER
SEALER OR FIRST BASECOAT (DRC OR SPRAY) ②
OVEN ⑤
SANDER
FIRST OR SECOND BASECOAT (DRC) ②
OVEN
INKS (OFFSET GRAVURE) ③
TOPCOAT (DRC) ④
INKS (OFFSET GRAVURE) ③
TOPCOAT ④
OVEN ⑤
COOLING
INSPECTION
PACKAGING
SHIPMENT

RRC = Reverse roll coating
DRC = Direct roll coating

Figure 4.2-6. Flatwood Interior Panel Coating Line Emission Points[14]

interior paneling, except that a primer sealer is applied to the filled panel, normally by direct roll coating; the panel is then embossed and valley printed to give a distressed or antique appearance (no basecoat is required). A sealer is also applied following printing but prior to application of the topcoat, which may be curtain coated (although direct roll coating remains the usual technique).

4.2.6.2 Emissions and Controls[8,14] - Emissions of volatile organic compounds (VOC) at flat wood coating plants occur primarily from (1) reverse roll coating of filler, (2) direct roll coating of sealer and basecoat, (3) printing of wood grain patterns, (4) direct roll or curtain coating of topcoat(s), and (5) oven drying after one or more of these operations (these numbers refer to Figure 4.2-6). All solvent used and not recovered can be considered as potential emissions. Emissions can be calculated from the factors in Table 4.2-1 if the coating usage is known. Emissions for interior printed panels can be estimated from the factors in Table 4.2-11 if the total area of coated panels is known.

Water-borne coatings, as a change in process materials to reduce emissions, are increasing in usage and can be applied to almost all flat wood, with the exception of redwood and possibly cedar. The major use of water-borne flat wood coatings is in the filler and basecoat applied to printed interior paneling. Limited use has been made of water-borne materials for inks, groove coats, and topcoats for printed paneling, and for inks and groove coats for natural hardwood panels.

Ultraviolet curing systems are applicable for clear to semitransparent fillers, topcoats on particleboard coating lines, and in specialty coating operations. Polyester, acrylic, urethane, and alkyd coatings can be cured by this method.

Table 4.2-11. VOC EMISSION FACTORS FOR INTERIOR PRINTED PANELS[14]
EMISSION FACTOR RATING: B

Paint Category	Coverage[a]				Uncontrolled VOC Emissions					
	liter/100 m^2		gal/1,000 ft^2		kg/100 m^2 coated			lb/1,000 ft^2 coated		
	Water-borne	Conventional Paint	Water-borne	Conventional Paint	Water-borne	Conventional Paint	Ultra-violet[b]	Water-borne	Conventional Paint	Ultra-violet[b]
Filler	6.5	6.9	1.6	1.7	0.3	3.0	nil	0.6	6.1	nil
Sealer	1.4	1.2	0.35	0.3	0.2	0.54	0	0.4	1.1	0
Basecoat	2.6	3.2	0.65	0.8	0.2	2.4	0.24	0.5	5.0	0.5
Ink	0.4	0.4	0.1	0.1	0.1	0.3	0.10	0.2	0.6	0.2
Topcoat	2.6	2.8	0.65	0.7	0.4	1.8	nil	0.9	3.7	nil
Total	13.7	14.7	3.4	3.6	1.2	8.0	0.4	2.6	16.5	0.8

[a] Paint coverage based on information by Reference 1 from Abitibi Corp., Cucamonga, CA. Adjustments between water and conventional paints were made using typical nonvolatiles content.

[b] UV line uses no sealer, uses water-borne basecoat and ink. Total is adjusted to cover potential emissions from the UV coatings.

Afterburners can be used to control VOC emissions from baking ovens, and there would seem to be ample opportunity for using recovered heat. Extremely few flat wood coating operations have afterburners as add-on controls, however, despite the fact that they are a viable control option for reducing emissions where other control techniques are not applicable due to product requirements.

Carbon adsorption is technically feasible, especially for specific applications (e.g., in redwood surface treatment), but multicomponent solvents and the use of different coating formulations in the several steps along the coating line have thus far precluded its use to control flat wood coating emissions by reclaiming solvents. The use of low solvent coatings to fill pores and seal wood has been demonstrated, but they do not appear practicable for current use in the flat wood coating industry. Costs of both the installed system and the coating itself limit the applicability of electron beam (EB) curing as a control technique.

4.2.7 Paper Coating

4.2.7.1 Process Description[5,7] - Paper is coated for a variety of decorative and functional purposes using water-borne, organic solvent-borne, or solventless extrusion type materials. Paper coating is not to be confused with printing operations, which use contrast coatings that must show a difference in brightness with the paper to be visible and thus convey their message to the observer. Moreover, inks are always applied with a printing machine.

Water-borne coatings improve printability and gloss, but cannot compete with organic solvent-borne coatings in terms of weather, scuff, and chemical resistance. Solvent-borne coatings have the added advantage of permitting a wide range of surface textures. Most solvent-borne coating is done by paper converting companies that buy paper from mills and apply coatings to produce a final product. Among the products that are coated using solvents are adhesive tapes and labels, decorated paper, book covers, zinc oxide-coated office copier paper, carbon paper, typewriter ribbons, and photographic films.

Organic solvent formulations generally used are made up of film-forming materials, plasticizers, pigments, and solvents. The main classes of film formers used in paper coating are cellulose derivatives (usually nitrocellulose) and vinyl resins (usually the copolymer of vinyl chloride and vinyl acetate). Three common plasticizers are dioctyl phthalate, tricresyl phosphate, and castor oil. The major solvents used are toluene, xylene, methyl ethyl ketone, isopropyl alcohol, methanol, acetone, and ethanol. Although a single solvent is frequently used, a solvent mixture is often necessary to obtain the optimum drying rate, flexibility, toughness, and abrasion resistance.

A variety of low solvent coatings with negligible emissions have been developed for some uses that can form organic resin films equal to those of conventional solvent-borne coatings. They can be applied up to 1/8-inch thick (usually by reverse roller coating) to make products such as artificial leather goods, book covers, and carbon paper. Smooth hot melt finishes can be applied over rough textured paper by heated gravure or roll coaters at temperatures from 60 to 230°C (150 to 450°F).

Plastic extrusion coating is a type of hot melt coating in which a molten thermoplastic sheet (usually low or medium density polyethylene) is extruded from a from a slotted dye at temperatures of up to 315°C (600°F). The moving substrate and the molten plastic are combined in a nip between a rubber roll and a chill roll.

Hundreds of products are coated with solventless extrusion coatings; an example is the polyethylene-coated milk carton.

Figure 4.2-7 shows a typical paper coating line that uses organic solvent-borne formulations. The application device is usually a reverse roller (as illustrated), a knife (refer to inset), or a rotogravure printer. A knife coater can apply solutions of much higher viscosity than roll coaters, thus emitting less solvent per pound of solids applied. The gravure printer can print patterns or a solid sheet of color on a paper web.

Ovens may be divided into two to five temperature zones. The first zone is usually at about 43°C (110°F); other zones have progressively higher temperatures that cure the coating after most of the solvent has evaporated. The typical curing temperature is 120°C (250°F); ovens are generally limited to operating temperatures of 200°C (400°F) to avoid damage to most types of paper. Although natural gas is the fuel most often used for direct-fired ovens, fuel oil is sometimes used. Some of the heavier grades of fuel oil can create problems because SO_2 and particulate may contaminate the paper coating. Distillate fuel oil usually can be used satisfactorily. Steam produced from burning the solvent that is retrieved from an adsorber or vented to an incinerator may also be used to heat curing ovens.

4.2.7.2 Emissions and Controls[7] - The main emission points from paper coating lines are (1) the coating applicator and (2) the oven (these numbers refer to Figure 4.2-7). In a typical paper coating plant, about 70 percent of all solvents used are emitted from the coating lines; most of these come from the first zone of the oven. The other 30 percent are emitted from solvent transfer, storage, and mixing operations and can be reduced through good

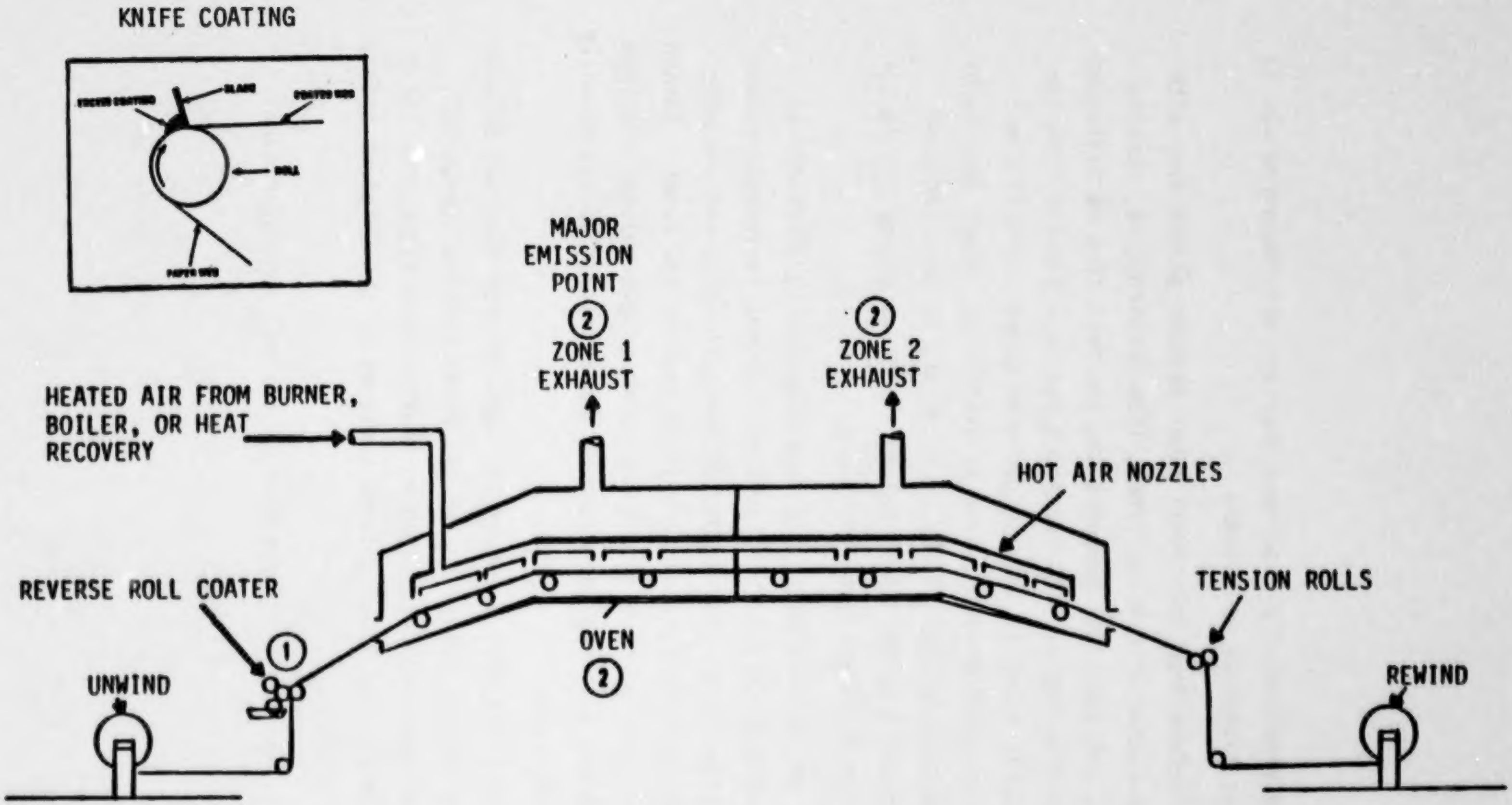

KNIFE COATING
MAJOR EMISSION POINT
②
ZONE 1 EXHAUST
②
ZONE 2 EXHAUST
HEATED AIR FROM BURNER, BOILER, OR HEAT RECOVERY
HOT AIR NOZZLES
REVERSE ROLL COATER
①
TENSION ROLLS
OVEN
②
UNWIND
REWIND

Figure 4.2-7. Paper Coating Line Emission Points[7]

housekeeping practices. All solvent used and not recovered can be considered as potential emissions.

VOC emissions from individual paper coating plants vary with the size and number of coating lines, line construction, coating formulation, and substrate composition, and must thus be evaluated on a case-by-case basis. VOC emissions can be estimated from the factors in Table 4.2-1 if coating usage is known and sufficient information on coating composition is available. Since many paper coatings are proprietary, it may be necessary to have the user supply information on the total solvent used and employ the factor from Table 4.2-12 to estimate emissions.

Almost all solvent emissions from the coating lines can be collected and sent to a control device. Thermal incinerators have been retrofitted to a large number of oven exhausts, with primary and even secondary heat recovery systems heating the ovens. Carbon adsorption is most adaptable to lines using single solvent coatings, although solvent mixtures collected by adsorbers can be subsequently distilled for reuse.

Although applicable for certain types of products, low solvent coatings are not yet available for all paper coating operations. The nature of some products, such as photographic films, may limit their adaptability to lower solvent coatings or to efficient add-on controls.

Table 4.2-13 lists efficiencies of several control devices.

Table 4.2-12. SOLVENT EMISSIONS FROM UNCONTROLLED PAPER COATING LINES
EMISSION FACTOR RATING: D

Solvent Emissions	
kg/MT solvent used[a]	lb/ton solvent used[a]
1,000	2,000

[a] Composition of coatings is usually proprietary.

Table 4.2-13. CONTROL EFFICIENCIES FOR PAPER COATING LINES[7]

Affected Facility	Control Technique	Percentage Reduction
Coating line	Incineration	95
	Carbon adsorption	90+
	Low solvent coatings	80-99[a]

[a] Based on comparison with a conventional coating containing 35 percent solids and 65 percent organic solvent by volume.

4.2.8 Fabric Coating

4.2.8.1 Process Description[7,15] - Fabric coating consists of coating a textile substrate to impart properties such as strength stability, water or acid repellancy, or appearance. This includes vinyl coating, which refers to any printing or decorative or protective topcoat applied over vinyl coated fabric or vinyl sheets, but does not include the application of the vinyl plastisol to the fabric, which produces negligible emissions.

Products that involve fabric coating include rainwear, tents, industrial and electrical tapes, tire cord, seals and gaskets, imitation leathers, shoe material, and upholstery fabrics. The industry is comprised mostly of small to moderate sized plants, many of which are toll coaters rather than specialists in a particular product line.

Figure 4.2-8 is a flow chart of a typical fabric coating operation. If the fabric is to be coated with rubber, the rubber is milled with pigments, curing agents, and fillers prior to being dissolved (mixed) in a suitable solvent; when nonrubber coatings are employed, milling is rarely necessary.

Coatings are normally applied by means of a knife, a roller, or a rotogravure printer. In addition, U.S. plants have recently begun to apply heat-transfer printing to textiles by the gravure process: the pattern is applied to dry-transfer paper, then heated to volatilize it onto the fabric. Flat and rotary screen printing processes are also used to print textiles. Screen printing employs a fine screen for the image area, through which ink or paint is forced; nonimage areas are produced by coating the screen to mask off the ink. Water-based emulsions and, more frequently, resin-bonded pigments are used with fabric screen printing.

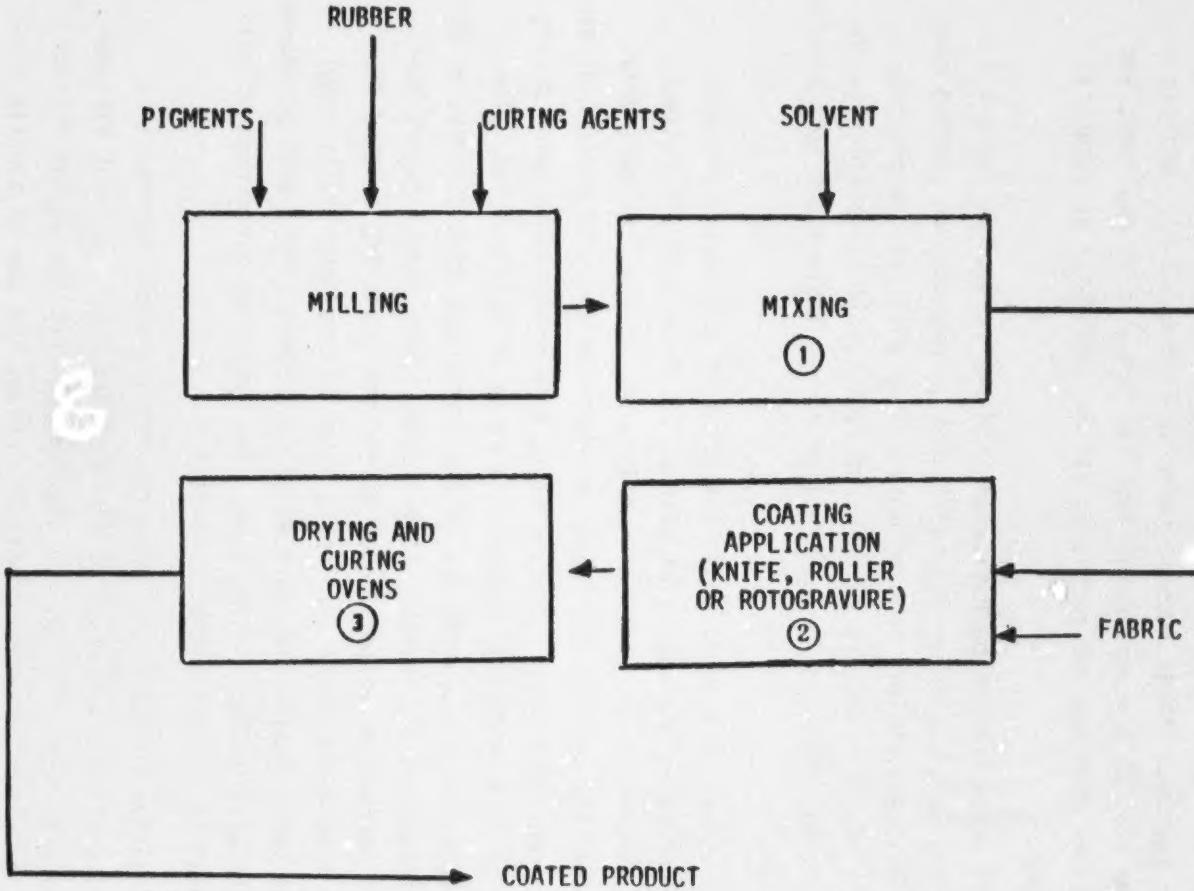

RUBBER
PIGMENTS
CURING AGENTS
SOLVENT
MILLING
MIXING
①
COATING
APPLICATION
(KNIFE, ROLLER
OR ROTOGRAVURE)
②
FABRIC
DRYING AND
CURING
OVENS
③
COATED PRODUCT

Figure 4.2-8. Fabric Coating Line Emission Points[7]

4.2.8.2 Emissions and Controls[7] - The VOC emissions in a fabric coating plant occur at (1) the mixer, (2) the coating applicator, and (3) the oven (these numbers refer to Figure 4.2-8). Emissions from the coating process depend upon the formulation employed, and all solvent used and not recovered can be considered as potential emissions.

VOC emissions can be estimated from the factors in Table 4.2-1 if coating usage is known and sufficient information on coating composition is available. Because many fabric coatings are proprietary, it may be necessary to have the user supply information on the total solvent used and employ the factor from Table 4.2-1 to estimate emissions.

Sometimes only small emissions occur at the mixer, but some vinyl coaters estimate that as much as 25 percent of all solvents used in the plant are emitted in mixing operations. Solvent emissions from the coating applicator account for 25 to 35 percent of all solvent emitted from the coating line, with rotogravure being a large source of such emissions compared to knife or roll coating. The major emission point, however, is the drying and curing ovens, at 65 to 75 percent of all coating line losses. Some plants report that over 70 percent of solvents used within the plant are emitted from the coating applicators and ovens; other plants, especially vinyl coating ones, report that only 40 to 60 percent of solvents purchased are emitted from the coating line. The remaining percentage of solvent used is lost as fugitive emissions.

Fugitive losses result from solvent transfer, storage tank breathing losses, agitation of mixing tanks, waste solvent disposal, various stages of cleanup, and evaporation from the coated fabric after it leaves the line. Controls include the use of tightly fitting covers for open tanks, collection hoods for cleanup areas, and closed containers for solvent wiping cloths.

Ovens heated by natural gas, steam, or electricity are used to dry and cure the coated fabric. Oven evaporation rates are often controlled to produce desired chemical changes in the coating solids (curing). In most ovens, almost all solvent emissions are captured and vented with exhaust gases; coating applicator emissions may also be ducted to the oven and included with the oven exhaust.

Incineration is probably the most viable control option for coating application and curing on commission coating lines, which use a variety of coating formulations to comply with customer specifications. The primary and secondary heat recovery and higher solvent concentrations in exhaust gases that are results of this control option help reduce the fuel requirements of the coating process.

As with other surface coating operations, carbon adsorption is most applicable to sources which use a single solvent blend that can be recovered for reuse.

Where high solids or water-borne coatings have been developed that can replace conventional coatings, their use may preclude the need for a control device.

Table 4.2-14. SOLVENT EMISSIONS FROM UNCONTROLLED
FABRIC COATING PLANTS
EMISSION FACTOR RATING: D

Solvent Emissions	
kg/MT solvent used[a]	lb/ton solvent used[a]
1,000	2,000

[a] Composition of coatings is usually proprietary.

References for Section 4.2

1. Products Finishing Directory, Volume 41, No. 6A. 600 Main Street, Cincinnati, Ohio, March 1977, pp. 4-54.

2. Controlling Pollution from the Manufacturing and Coating of Metal Products: Metal Coating Air Pollution Control-1. EPA-625/3-77-009. U.S. Environmental Protection Agency, Environmental Research Information Center, Technology Transfer, May 1977, Chapter 2.

3. Powers, H.R., "Economic and Energy Savings Through Coating Selection." The Sherwin-Williams Company, Chicago, Illinois 60628, February 8, 1978.

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5. Hughes, T.W.; Horn, D.A.; Sandy, C.W.; and Serth, R.W. Source Assessment: Prioritization of Air Pollution from Industrial Surface Coating Operations. EPA-650/2-75-019a. Monsanto Research Corporation, Dayton, Ohio. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711 under Contract No. 68-02-1320, February 1975.

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8. Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. Emission Standards and Engineering Division, OAQPS, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, May 27, 1977.

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10. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes. TRC of New England, Wethersfield, Conn. 06109. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, under Contract No. 68-02-1382, Task Order 12, September 1976, pp. XI-1-XI-3.

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15. Carpenter, B.H. and Hilliard, G.K. "Environmental Aspects of Chemical Use in Printing Operations." EPA-560/1-75-005 (PB 251406). U.S. Environmental Protection Agency, Washington, D.C. 20460, January 1976, pp. 5-30.

BACKGROUND DOCUMENT

SECTION 4.2 INDUSTRIAL SURFACE COATING

1.0 INTRODUCTION

The section on Industrial Surface Coating is organized as eight separate sections, as follows:

4.2.1 General
4.2.2 Coil and Can Coating
4.2.3 Magnet Wire Coating
4.2.4 Auto and Light-Duty Truck Coating
4.2.5 Other Metal Coating
4.2.6 Flat Wood Interior Panel Coating
4.2.7 Paper Coating
4.2.8 Fabric Coating

The section titles correspond to several of the subjects in a series of OAQPS Guideline Documents for the control of volatile organic emissions from existing stationary sources (References 6, 7, 9 and 11-14). These documents were used as primary information sources for the preparation of this section.

2.0 GENERAL SURFACE COATING (Tables 4.2-1 to 4.2-3)

Section 4.2.1 contains no emission factors per se. It does contain information on the densities and volatile organic contents of coatings and formulas for using this information to compute VOC emissions on the assumption that all the VOC in a coating are evaporated. No claims are made for the "representativeness" of these compositional data. They are quoted directly from AP-40, Second ed. (Reference 4, p. 864), which is assumed to be authoritative and accurate.

3.0 COIL AND CAN COATING (Tables 4.2-4 and 4.2-5)

The emissions from can coating that are summarized in Table 4.2-4 of Section 4.2.2 are taken directly from Table 2-2, page 2-15 of Volume II of the EPA's Control of Volatile Organic Emissions From Existing Stationary Sources (Reference 7).

The data contained in Table 4.2-5 are taken from pages 2-1 and 2-2 of Reference 7. The author of Reference 7 estimated emissions and control efficiencies from data contained in trip reports prepared by EPA personnel V.N. Gallagher and W.L. Johnson. The data presumably represent typical values based on the best engineering judgments of the authors of the reports.

Coil and can coating were considered together because they both involve the industrial surface coating of metal sheets or webs on coating lines that usually consist of roll coaters and drying ovens.

4.0 MAGNET WIRE COATING (Table 4.2-6)

The wire coating emissions presented in Table 4.2-6 are taken directly from Table 3-1, page 3-3 of Reference 9. Tons per year were computed from the operating factor of 7,000 hr/yr given in Table 3-1.

5.0 AUTOMOBILE AND LIGHT-DUTY TRUCK COATING (Tables 4.2-7 and 4.2-8)

The emissions data presented in Table 4.2-7 of Section 4.2.4 are taken directly from Reference 7, Figure 6.3, page 6-15, and the control efficiencies given in Table 4.2-8 are taken from page 6-1 of Reference 7.

No specific sources for individual data items are given in Reference 7, but nearly all data sources for this document are listed as comments from industry or as trip reports from EPA personnel. Presumably the data in Tables 4.2-7 and 4.2-8 are derived from the industry comments, the EPA trip reports, and the best engineering judgment of the authors of Reference 7.

Auto refinishing/topcoat repair is not included in this section because repair production is intermittent and generally limited to manual spraying with solvent-borne coatings that can be dried at temperatures low enough for the trim to tolerate.

6.0 OTHER METAL COATING (Tables 4.2-9 and 4.2-10)

The emission factors in Table 4.2-9 were computed from information in Reference 11, Table 3-1, Reference 12, Tables 3-3 an 3-4, and Reference 13, Tables 3-3 to 3-9. In each case, the reference gave information about the number of tons of VOC removed by controls and also gave the percentage reduction based on uncontrolled emissions. The tons of uncontrolled VOC were computed from these two data items. The production rates are those given in References 11, 12, and 13 for model plants. No references or other justification are given for the technical parameters listed for these plants, but presumably they represent the best engineering judgment of the authors of References 11, 12, and 13.

Table 4.2-10 is compiled from data taken directly from Reference 11 (page 2-1), Reference 12 (page 2-1), and Reference 13 (page 2-1). No specific documentation is given for any of these data, but, in general, they are based on trip reports and comments from industry.

7.0 FLAT WOOD INTERIOR PANEL COATING (Table 4.2-11)

The information in Tables 4.2-11 of Section 4.2.6 is taken directly from page 2-4 of Volume VII of the series cited above (Reference 14), which, in turn, is based on information supplied by industry.

8.0 PAPER COATING (Tables 4.2-12 and 4.2-13)

The information in Table 4.2-12 of Section 4.2.7 is based on the premise of mass balance, and the information in Table 4.2-13 is taken directly from page 5-1 of Reference 7. The primary sources for these data are not given in Reference 7.

9.0 FABRIC COATING (Table 4.2-14)

The information in Table 4.2-14 of Section 4.2.8 is based on the premise of mass balance. No estimates of emissions from fabric coating lines were presented in the reference documents on which this section is based (i.e., References 7 and 15; the latter consists of one chapter of EPA's "Environmental Aspects of Chemical Use In Printing Operations").

4.4 TRANSPORTATION AND MARKETING OF PETROLEUM LIQUIDS[1]

4.4.1 Process Description

As Figure 4.4-1 indicates, the transportation and marketing of petroleum liquids involves many distinct operations, each of which represents a potential source of hydrocarbon evaporation loss. Crude oil is transported from production operations to the refinery via tankers, barges, tank cars, tank trucks, and pipelines. In the same manner, refined petroleum products are conveyed to fuel marketing terminals and petrochemical industries by tankers, barges, tank cars, tank trucks, and pipelines. From the fuel marketing terminals, the fuels are delivered via tank trucks to service stations, commercial accounts, and local bulk storage plants. The final destination for gasoline is usually a motor vehicle gasoline tank. A similar distribution path may also be developed for fuel oils and other petroleum products.

4.4.2 Emissions and Controls

Evaporative hydrocarbon emissions from the transportation and marketing of petroleum liquids may be separated into four categories, depending on the storage equipment and mode of transportation used:

1. Large storage tanks: Breathing, working, and standing storage losses.
2. Marine vessels, tank cars, and tank trucks: Loading, transit, and ballasting losses.
3. Service stations: Bulk fuel drop losses and underground tank breathing losses.
4. Motor vehicle tanks: Refueling losses.

(In addition, evaporative and exhaust emissions are also associated with motor vehicle operation. These topics are discussed in Chapter 3.)

4.4.2.1 Large Storage Tanks - Losses from storage tanks are thoroughly discussed in Section 4.3.

4.4.2.2 Marine Vessels, Tank Cars, and Tank Trucks - Losses from marine vessels, tank cars, and tank trucks can be categorized into loading losses, transit losses, and ballasting losses.

Loading losses are the primary source of evaporative hydrocarbon emissions from marine vessel, tank car, and tank truck operations. Loading losses occur as hydrocarbon vapors residing in empty cargo tanks are displaced to the atmosphere by the liquid being loaded into the cargo tanks. The hydrocarbon vapors displaced from the cargo tanks are a composite of (1) hydrocarbon vapors formed in the empty tank by evaporation of residual product from previous hauls and (2) hydrocarbon vapors generated in the tank as the new product is being loaded. The quantity of hydrocarbon losses from loading operations is, therefore, a function of the following parameters:

- Physical and chemical characteristics of the previous cargo.
- Method of unloading the previous cargo.

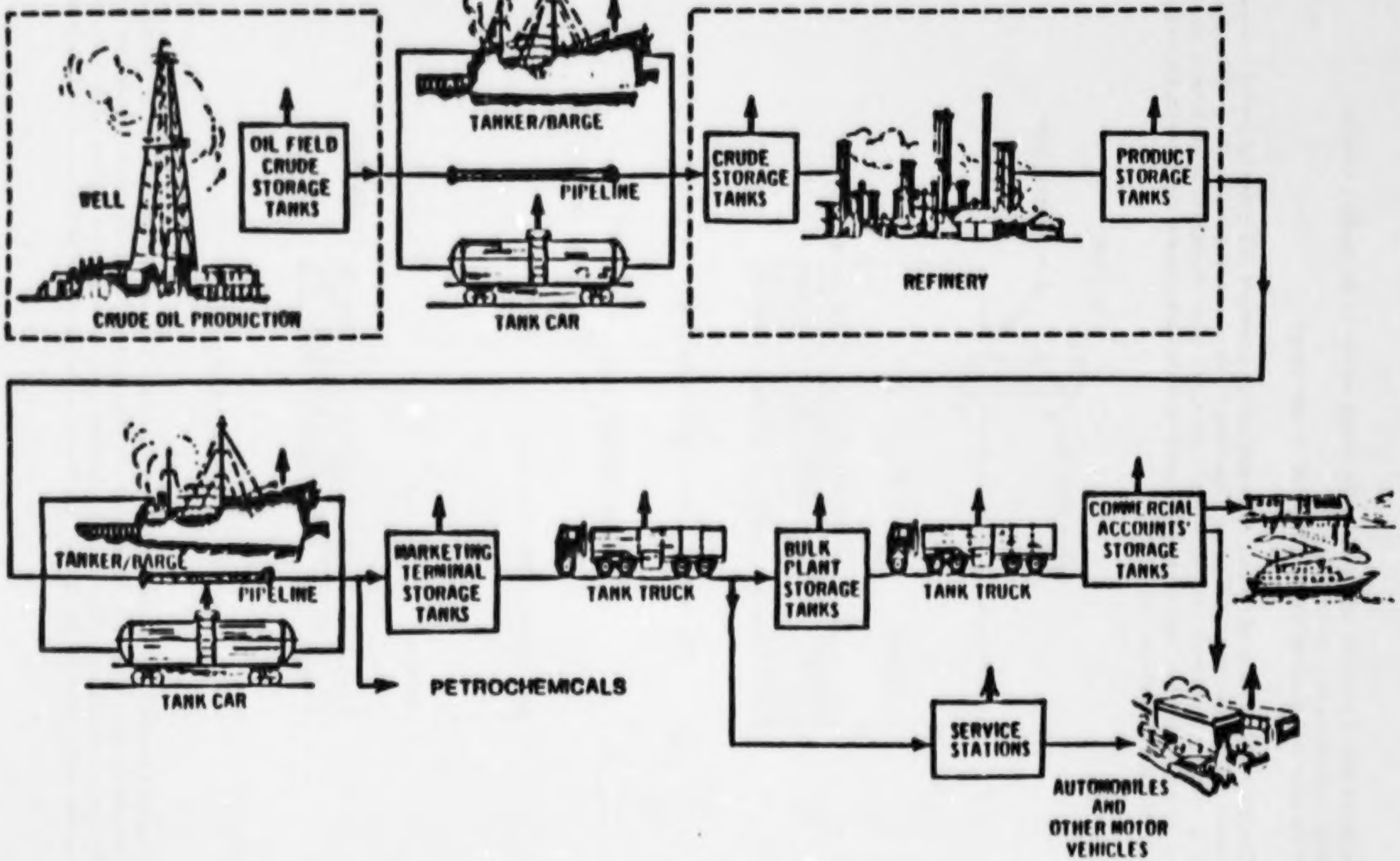
WELL
OIL FIELD CRUDE STORAGE TANKS
CRUDE OIL PRODUCTION
TANKER/BARGE
PIPELINE
TANK CAR
CRUDE STORAGE TANKS
REFINERY
PRODUCT STORAGE TANKS
TANKER/BARGE
PIPELINE
TANK CAR
PETROCHEMICALS
MARKETING TERMINAL STORAGE TANKS
TANK TRUCK
BULK PLANT STORAGE TANKS
TANK TRUCK
COMMERCIAL ACCOUNTS' STORAGE TANKS
SERVICE STATIONS
AUTOMOBILES AND OTHER MOTOR VEHICLES

Figure 4.4-1. Flowsheet of petroleum production, refining, and distribution systems. (Sources of organic evaporative emissions are indicated by vertical arrows.)

- Operations during the transport of the empty carrier to the loading terminal.
- Method of loading the new cargo.
- Physical and chemical characteristics of the new cargo.

The principal methods of loading cargo carriers are presented in Figures 4.4-2, 4.4-3, and 4.4-4. In the splash loading method, the fill pipe dispensing the cargo is only partially lowered into the cargo tank. Significant turbulence and vapor-liquid contacting occurs during the splash loading operation, resulting in high levels of vapor generation and loss. If the turbulence is high enough, liquid droplets will be entrained in the vented vapors.

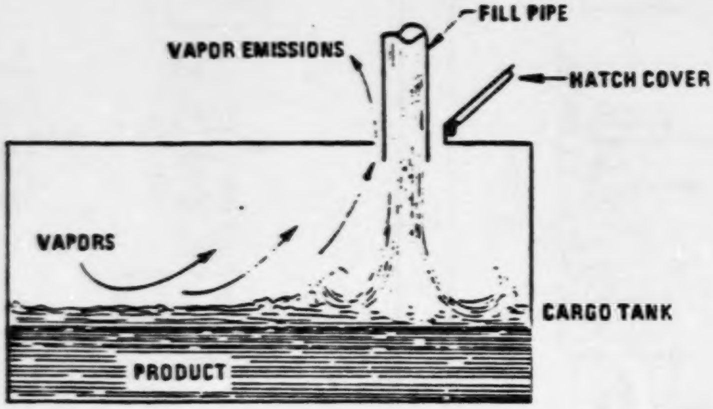
FILL PIPE
VAPOR EMISSIONS
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Figure 4.4-2. Splash loading method.

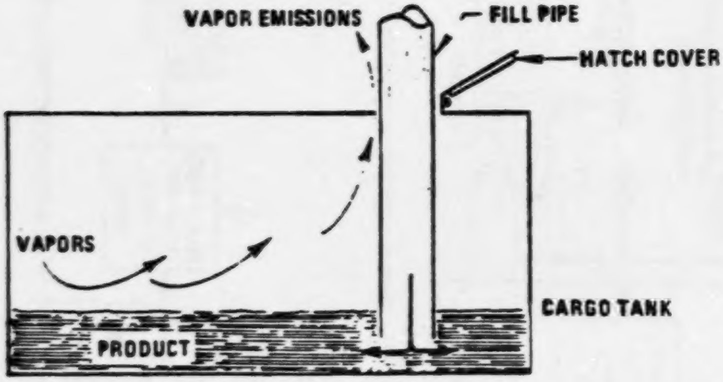
VAPOR EMISSIONS
FILL PIPE
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Figure 4.4-3. Submerged fill pipe.

A second method of loading is submerged loading. The two types of submerged loading are the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe descends almost to the bottom of the cargo tank. In the bottom loading method, the fill pipe enters the cargo tank from the bottom. During the major portion of both forms of submerged loading

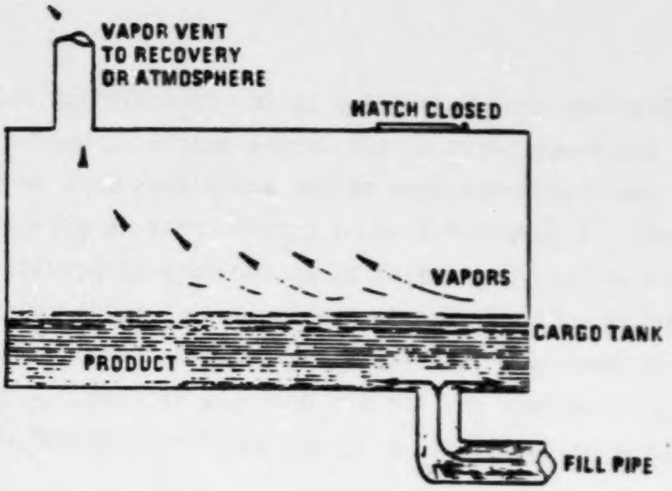

Figure 4.4-4. Bottom loading.

methods, the fill pipe opening is positioned below the liquid level. The submerged loading method significantly reduces liquid turbulence and vapor-liquid contacting, thereby resulting in much lower hydrocarbon losses than encountered during splash loading methods.

The history of a cargo carrier is just as important a factor in loading losses as the method of loading. If the carrier has just been cleaned or has carried a nonvolatile liquid such as fuel oil, it will be full of clean air immediately prior to loading; if it has just carried gasoline and has not been vented, the carrier will be full of air saturated with hydrocarbon vapor. In the latter case, the residual vapors are expelled along with newly generated vapors during the subsequent loading operation.

Some cargo carriers are dedicated to the transport of only one product. In this situation, tanks are not cleaned between each trip and so return for loading containing air fully or partially saturated with vapor. The degree of dedication differs for marine vessels, tank cars, and large and small tank trucks. It also varies with ownership of the carrier, petroleum liquid being transported, geographic location, season of the year, and control measure employed.

Gasoline tank trucks may be in "dedicated balance service," where the truck picks up the vapors displaced during unloading operations and transports them in the empty tank back to the loading terminal. Figure 4.4-5 shows a tank truck in dedicated vapor balance service unloading gasoline to an underground service station tank and filling up with displaced gasoline vapors to be returned to the truck loading terminal. The vapors in an empty gasoline tank truck in dedicated balance service are normally saturated with hydrocarbons. Dedicated balance service is not usually practiced with marine vessels.

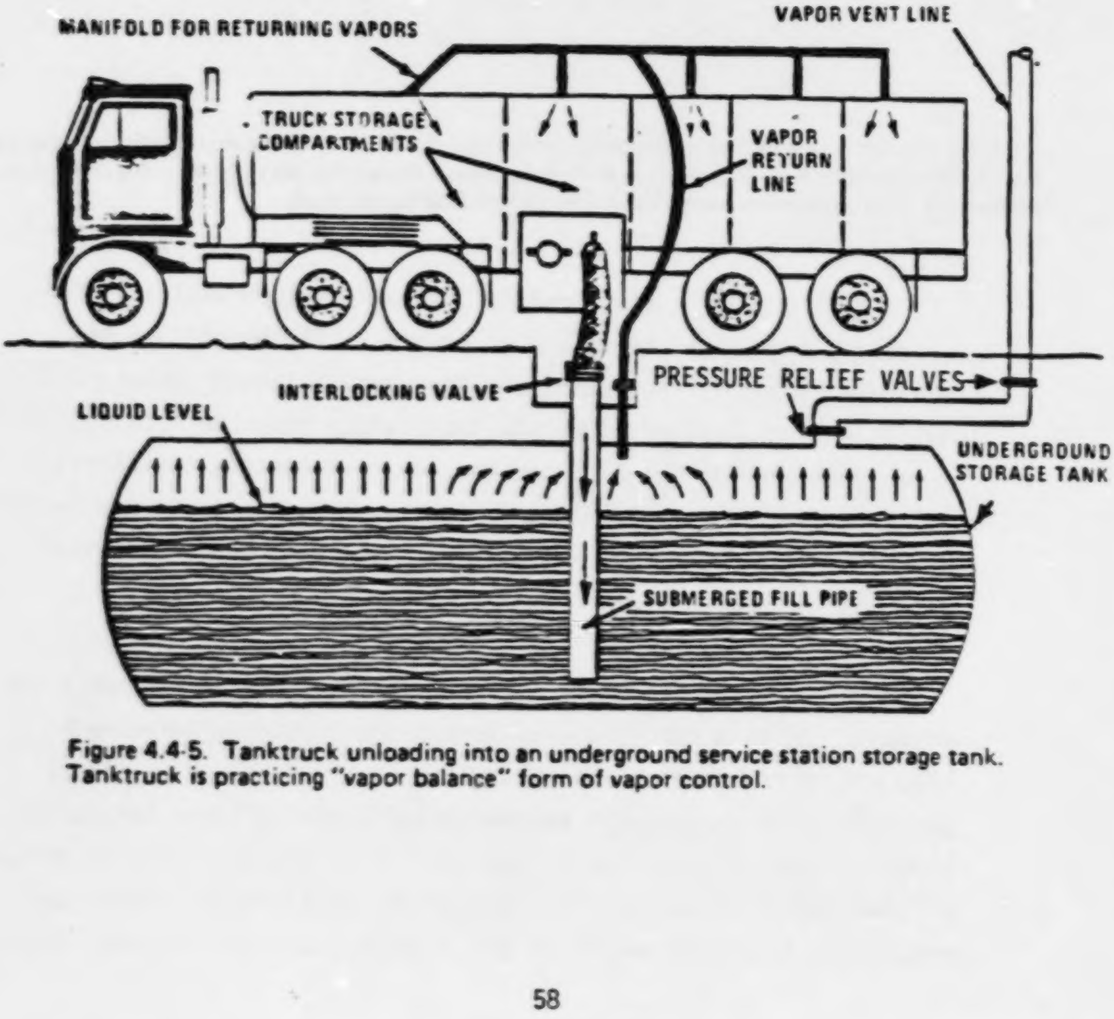
MANIFOLD FOR RETURNING VAPORS
VAPOR VENT LINE
TRUCK STORAGE COMPARTMENTS
VAPOR RETURN LINE
INTERLOCKING VALVE
PRESSURE RELIEF VALVES
LIQUID LEVEL
UNDERGROUND STORAGE TANK
SUBMERGED FILL PIPE

Figure 4.4-5. Tanktruck unloading into an underground service station storage tank. Tanktruck is practicing "vapor balance" form of vapor control.

Emissions from loading hydrocarbon liquid can be estimated (within 30 percent) using the following expression:

$$L_L = 12.46 \frac{SPM}{T} \qquad (1)$$

where: L_L = Loading loss, lb/10^3 gal of liquid loaded.

M = Molecular weight of vapors, lb/lb-mole (see Table 4.3-1).

P = True vapor pressure of liquid loading, psia (see Figures 4.3-8 and 4.3-9, and Table 4.3-1).

T = Bulk temperature of liquid loaded, °R.

S = A saturation factor (see Table 4.4-1).

The saturation factor (S) represents the expelled vapor's fractional approach to saturation and accounts for the variations observed in emission rates from the different unloading and loading methods. Table 4.4-1 lists suggested saturation factors (S).

Table 4.4-1. S FACTORS FOR CALCULATING PETROLEUM LOADING LOSSES

Cargo carrier	Mode of operation	S factor
Tank trucks and tank cars	Submerged loading of a clean cargo tank	0.50
	Splash loading of a clean cargo tank	1.45
	Submerged loading: normal dedicated service	0.60
	Splash loading: normal dedicated service	1.45
	Submerged loading: dedicated, vapor balance service	1.00
	Splash loading: dedicated, vapor balance service	1.00
Marine vessels[a]	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

[a] To be used for products other than gasoline; use factors from Table 4.4-2 for marine loading of gasoline.

Ballasting operations are a major source of hydrocarbon emissions associated with unloading petroleum liquids at marine terminals. It is common practice for large tankers to fill several cargo tanks with water after unloading their cargo. This water, termed ballast, improves the stability of the empty tanker on rough seas during the subsequent return voyage. Ballasting emissions occur as hydrocarbon-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the empty cargo tank. Although ballasting practices vary quite a bit, individual cargo tanks are ballasted about 80 percent, and the total vessel is ballasted approximately 40 percent of capacity. Ballasting emissions from gasoline and crude oil tankers are approximately 0.8 and 0.6 lb/10^3 gal, respectively, based on total tanker capacity. These estimates are for motor gasolines and medium volatility crudes (RVP$\approx$5 psia).[2] Upon arrival in port, this ballast water is pumped from the cargo tanks before loading the new cargo. The ballasting of cargo tanks reduces the quantity of vapor returning in the empty tanker, thereby reducing the quantity of vapors emitted during subsequent tanker loading operations.

Recent studies on gasoline loading losses from ships and barges have led to the development of more accurate emission factors for these specific loading operations. These factors are presented in Table 4.4-2 and should be used instead of Equation (1) for gasoline loading operations at marine terminals.[3]

Table 4.4-2. HYDROCARBON EMISSION FACTORS FOR GASOLINE LOADING OPERATIONS

Vessel tank condition	Hydrocarbon emission factors					
	Ships		Ocean barges		Barges	
	Range	Average	Range	Average	Range	Average
Cleaned and vapor free						
lb/10^3 gal transferred	0 to 2.3	1.0	0 to 3	1.3	a	1.2
kg/10^3 liter transferred	0 to 0.28	0.12	0 to 0.36	0.16		0.14
Ballasted						
lb/10^3 gal transferred	0.4 to 3	1.6	0.5 to 3	2.1	b	b
kg/10^3 liter transferred	0.05 to 0.36	0.19	0.06 to 0.36	0.25		
Uncleaned - dedicated service						
lb/10^3 gal transferred	0.4 to 4	2.4	0.5 to 5	3.3	1.4 to 9	4.0
kg/10^3 liter transferred	0.05 to 0.48	0.29	0.06 to 0.60	0.40	0.17 to 1.08	0.48
Average cargo tank condition						
lb/10^3 gal transferred	a	1.4	a	a	a	4.0
kg/10^3 liter transferred		0.17				0.48

[a] These values are not available

[b] Barges are not normally ballasted

Sample Calculation - Loading losses from a gasoline tank truck in dedicated balance service and practicing vapor recovery would be calculated as follows using Equation (1).

Design basis:

Tank truck volume is 8000 gallons
Gasoline RVP is 9 psia
Dispensing temperature is 80°F
Vapor recovery efficiency is 95%

Loading loss equation:

$$L_L = 12.46 \frac{SPM}{T} \left(1 - \frac{eff}{100}\right)$$

where: S = Saturation factor (see Table 4.4-1) = 1.0
P = True vapor pressure of gasoline (see Figure 4.3-8) = 6.6 psia
M = Molecular weight of gasoline vapors (see Table 4.3-1) = 66
T = Temperature of gasoline = 540°R
eff = The control efficiency = 95%

$$L_L = 12.46 \frac{(1.0)(6.6)(66)}{540} \left(1 - \frac{95}{100}\right)$$

$$= 0.50 \text{ lb}/10^3 \text{ gal}$$

Total loading losses are

$(0.50 \text{ lb}/10^3 \text{ gal}) (8.0 \times 10^3 \text{ gal}) = 4.0$ lb of hydrocarbon

Control measures for reducing loading emissions include the application of alternate loading methods producing lower emissions and the application of vapor recovery equipment. Vapor recovery equipment captures hydrocarbon vapors displaced during loading and ballasting operations and recovers the hydrocarbon vapors by the use of refrigeration, absorption, adsorption, and/or compression. Figure 4.4-6 demonstrates the recovery of gasoline vapors from tank trucks during loading operation at bulk terminals. Control efficiencies range from 90 to 98 percent depending on the nature of the vapors and the type of recovery equipment employed.[4]

Emissions from controlled loading operations can be calculated by multiplying the uncontrolled emission rate calculated in Equations (1) and (2) by the control efficiency term:

$$\left[1 - \frac{\text{efficiency}}{100}\right]$$

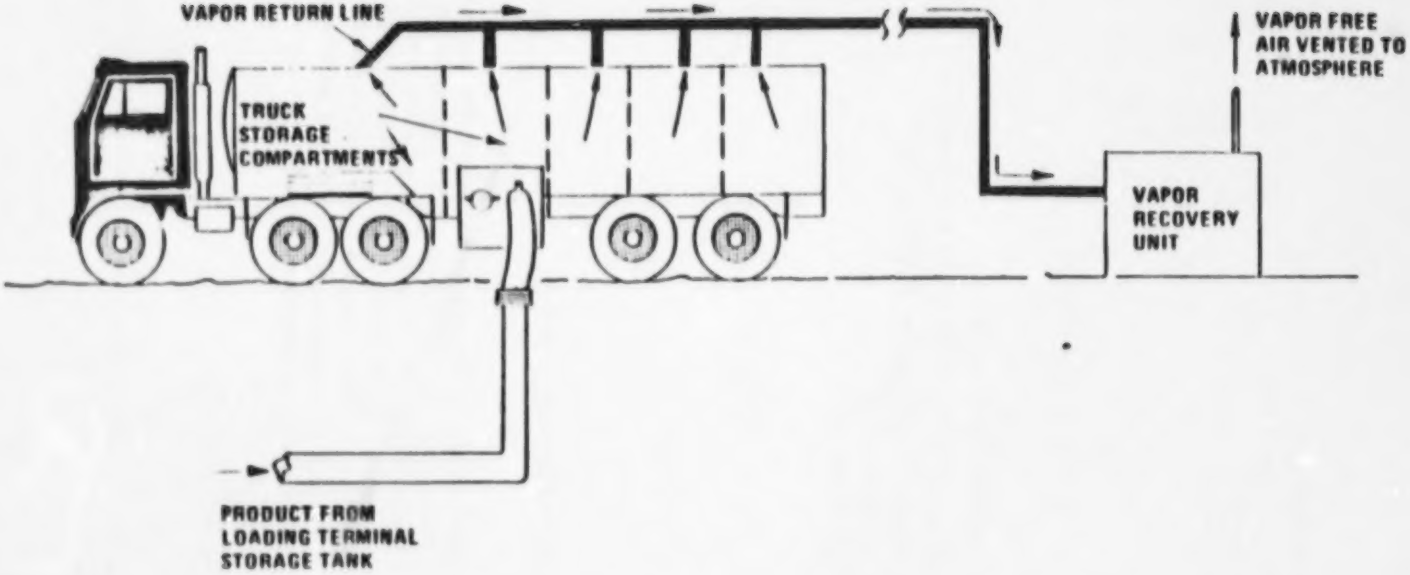
VAPOR RETURN LINE
TRUCK STORAGE COMPARTMENTS
VAPOR FREE AIR VENTED TO ATMOSPHERE
VAPOR RECOVERY UNIT
PRODUCT FROM LOADING TERMINAL STORAGE TANK

Figure 4.4.6. Tanktruck loading with vapor recovery.

In addition to loading and ballasting losses, losses occur while the cargo is in transit. Transit losses are similar in many ways to breathing losses associated with petroleum storage (refer to section 4.3). Experimental tests on tankers and barges have indicated that transit losses can be calculated using Equation (2):[3]

$$L_T = 0.1 PW \tag{2}$$

where: L_T = Transit loss, lb/week-10^3 gal transported.

P = True vapor pressure of the transported liquid, psia (see Figures 4.3-8 and 4.3-9, and Table 4.3-1).

W = Density of the condensed vapors, lb/gal (see Table 4.3-1).

In the absence of specific inputs for Equations (1) and (2), typical evaporative hydrocarbon emissions from loading operations are presented in Table 4.4-3. It should be noted that, although the crude oil used to calculate the emission values presented in Table 4.4-3 has an RVP of 5, the RVP of crude oils can range over two orders of magnitude. In areas where loading and transportation sources are major factors affecting the air quality it is advisable to obtain the necessary parameters and to calculate emission estimates from Equations (1) and (2).

Emissions from gasoline trucks have been studied by a combination of theoretical and experimental techniques,[7,8] and typical emission values are presented in Table 4.4-3. Emissions depend upon the extent of venting from the tank truck during transit, which in turn depends on the leak-tightness of the truck, the pressure relief valve settings, the pressure in the tank at the start of the trip, the vapor pressure of the fuel being transported, and the degree of saturation (with fuel vapor) of the vapor space in the tank. The emissions are not directly proportional to the time spent in transit: as the leakage rate of the truck increases, emissions increase up to a point and then level off as other factors take over in determining the rate. Tank trucks in dedicated vapor balance service typically contain saturated vapors; this leads to lower emissions during transit because no additional fuel evaporates to raise the pressure in the tank and cause venting. Table 4.4-3 lists "typical" values for emissions and also "extreme" values which could occur in the unlikely event that all factors that determine emissions had precisely the proper values to give maximum emissions.

4.4.2.3 Service Stations - Another major source of evaporative hydrocarbon emissions is the filling of underground gasoline storage tanks at service stations. Normally, gasoline is delivered to service stations in large (8000 gallon) tank trucks. Emissions are generated when hydrocarbon vapors in the underground storage tank are displaced to the atmosphere by the gasoline being loaded into the tank. As with other loading losses, the quantity of the service station tank loading loss depends on several variables including the size and length of the fill pipe, the method of filling, the tank configuration, and the gasoline temperature, vapor pressure, and composition. An average hydrocarbon emission rate for submerged filling is 7.3 lb/10^3 gallons of transferred gasoline, and the rate for splash filling is 11.5 lb/10^3 gallons of transferred gasoline (Table 4.4-4).[4]

Emissions from underground tank filling operations at service stations can be reduced by the use of the vapor balance system (Figure 4.4-5). The vapor balance system employs a vapor return hose which returns gasoline vapors displaced from the underground tank to the tank truck storage compartments being emptied. The control efficiency of the balance system ranges from 93 to 100 percent. Hydrocarbon emissions from underground tank filling operations at a service station employing the vapor balance system and submerged filling are not expected to exceed 0.3 lb/10^3 gallons of transferred gasoline.

Table 4.4-3. HYDROCARBON EMISSION FACTORS FOR PETROLEUM LIQUID TRANSPORTATION AND MARKETING SOURCES

Emission source	Product emission factors[a]					
	Gasoline[b]	Crude oil[c]	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Tank cars/trucks						
Submerged loading-normal service						
lb/10^3 gal transferred	5	3	1.5	0.02	0.01	0.0001
kg/10^3 liters transferred	0.6	0.4	0.18	0.002	0.001	0.00001
Splash loading-normal service						
lb/10^3 gal transferred	12	7	4	0.04	0.03	0.0003
kg/10^3 liters transferred	1.4	0.8	0.5	0.005	0.004	0.00004
Submerged loading-balance service						
lb/10^3 gal transferred	8	5	2.5	d	d	d
kg/10^3 liters transferred	1.0	0.6	0.3			
Splash loading-balance service						
lb/10^3 gal transferred	8	5	2.5	d	d	d
kg/10^3 liters transferred	1.0	0.6	0.3			
Transit-loaded with fuel						
lb/10^3 gas transferred	0-0.01 typical	e	e	e	e	e
	0-0.08 extreme	e	e	e	e	e
kg/10^3 liters transferred	0-0.001 typical	e	e	e	e	e
	0-0.009 extreme	e	e	e	e	e
Transit-return with vapor						
lb/10^3 gal transferred	0-0.11 typical	e	e	e	e	e
	0-0.37 extreme	e	e	e	e	e
kg/10^3 liters transferred	0-0.013 typical	e	e	e	e	e
	0-0.044 extreme	e	e	e	e	e
Marine vessels						
Loading tankers						
lb/10^3 gal transferred	f	0.07	0.05	0.005	0.005	0.00004
kg/10^3 liters transferred		0.08	0.06	0.0006	0.0006	5×10^{-6}
Loading Barges						
lb/10^3 gal transferred	f	1.7	1.2	0.0013	0.012	0.00009
kg/10^3 liters transferred	f	0.20	0.14	0.0016	0.0014	1.1×10^{-5}
Tanker ballasting						
lb/10^3 gal cargo capacity	0.8	0.6	e	e	e	e
kg/10^3 liters cargo capacity	0.10	0.07				
Transit						
lb/week - 10^3 gal transported	3	1	0.7	0.005	0.005	3×10^{-5}
kg/week - 10^3 liters transported	0.4	0.1	0.08	0.0006	0.0006	4×10^{-6}

[a] Emission factors are calculated for dispensed fuel temperature of 60°F.
[b] The example gasoline has an RVP of 10 psia.
[c] The example crude oil has an RVP of 5 psia.
[d] Not normally used.
[e] Not available.
[f] See Table 4.4-2 for these emission factors.

Table 4.4-4. HYDROCARBON EMISSIONS FROM GASOLINE SERVICE STATION OPERATIONS

Emission source	Emission rate lb/10^3 gal throughput	 kg/10^3 liters throughput
Filling underground tank		
Submerged filling	7.3	0.88
Splash filling	11.5	1.38
Balanced submerged filling	0.3	0.04
Underground tank breathing and emptying[a]	1	0.12
Vehicle refueling operations		
Displacement losses (uncontrolled)	9	1.08
Displacement losses (controlled)	0.9	0.11
Spillage	0.7	0.084

[a] Emissions include any vapor loss from the underground tank to the gas pump.

A second source of hydrocarbon emissions from service stations is underground tank breathing. Breathing losses occur daily and are attributed to temperature changes, barometric pressure changes, and gasoline evaporation. The type of service station operation also has a large impact on breathing losses. An average breathing emission rate is 1 lb/10^3 gallons throughput.[3]

4.4.2.4 Motor Vehicle Refueling - An additional source of evaporative hydrocarbon emissions at service stations is vehicle refueling operations. Vehicle refueling emissions are attributable to vapors displaced from the automobile tank by dispensed gasoline and to spillage. The quantity of displaced vapors is dependent on gasoline temperature, auto tank temperature, gasoline RVP, and dispensing rates. Although several correlations have been developed to estimate losses due to displaced vapors, significant controversy exists concerning these correlations. It is estimated that the hydrocarbon emissions due to vapors displaced during vehicle refueling average 9 lb/10^3 gallons of dispensed gasoline.[4,5]

The quantity of spillage loss is a function of the type of service station, vehicle tank configuration, operator technique, and operation discomfort indices. An overall average spillage loss is 0.7 lb/10^3 gallons of dispensed gasoline.[4].

Control methods for vehicle refueling emissions are based on conveying the vapors displaced from the vehicle fuel tank to the underground storage tank vapor space through the use of a special hose and nozzle (Figure 4.4-7). In the "balance" vapor control system, the vapors are conveyed by natural pressure differentials established during refueling. In "vacuum assist" vapor control systems, the conveyance of vapors from the auto fuel tank to the underground fuel tank is assisted by a vacuum pump. The overall control efficiency of vapor control systems for vehicle refueling emissions is estimated to be 88 to 92 percent.[4]

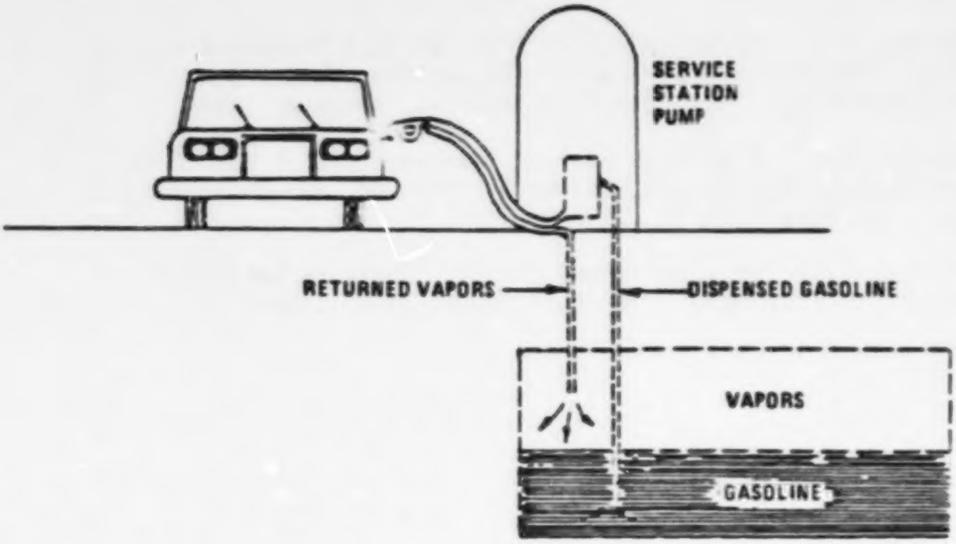

Figure 4.4-7. Automobile refueling vapor-recovery system.

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BACKGROUND DOCUMENT

TRANSIT LOSSES FROM GASOLINE TANK TRUCKS

1.0 INTRODUCTION

This document pertains only to the emission factors for transit losses from gasoline tank trucks presented in Table 4.4-3 of AP-42 and to the text that deals with these factors. The remainder of Section 4.4 was prepared by others, and the background for their calculations is found elsewhere.

2.0 THEORETICAL CALCULATIONS OF EMISSIONS

A theoretical analysis of truck transit breathing loss was made by Nichols[1] using an isothermal stirred tank as a model. Calculations were made for two situations: (1) where the tank has an open vent, and (2) where the tank has a P/V valve which prevents all venting until the valve opening pressure is reached and allows free venting thereafter.

2.1 TRANSIT WITH FULL FUEL LOADS[1, 2]

For truck transit with a full fuel load from the terminal, venting was assumed to occur until the fuel vapor space was saturated to the fuel vapor pressure. When this state is reached, no further pressure increases occur. The following equation was used to estimate losses from tanks with open vents and full fuel loads:

$$\text{gm/gal transferred} = 0.7057 \frac{V_G}{V_L} P \left[\ln\left(\frac{P - S_1 P_H^\circ}{P - S_2 P_H^\circ} \right) + \frac{P_H^\circ}{P} (S_1 - S_2) \right]$$

where V_G = vapor space volume

V_L = liquid fuel volume (same units as V_G)

P = atmospheric pressure, psia

S_1 = vapor saturation on leaving terminal, fraction of 1.00

S_2 = vapor saturation upon arrival at unloading station, fraction of 1.00

P_H° = fuel vapor pressure, psia

For losses from tanks with P/V valves and full fuel loads, the following equation was used:

$$\text{gm/gal transferred} = 0.7057 \frac{V_G}{V_L} P_v \left[\ln \left(\frac{P_v - S_1^* P_H^\circ}{P_v - S_2^* P_H^\circ} \right) + \frac{P_H^\circ}{P_v} (S_1^* - S_2^*) \right]$$

where symbols are as above and

P_v = vent opening pressure, psia

S_1^* = vapor saturation at the vent opening pressure on leaving terminal, fraction of 1.00

S_2^* = vapor saturation at the vent opening pressure upon arrival at unloading station, fraction of 1.00

The constant of 0.7057 in the equations contains the assumption that the temperature is 74.1°F (534.1°R) and the mole weight of the fuel vapor is 66.7 (lb m/lb mole).

Calculations were made for both situations using the following values. Since no experimental data base was available, a series of values was used for some of the parameters in an effort to cover the entire range of reasonable values.

$\frac{V_G}{V_L}$ = 0.05, 0.10, 0.15

P = 14.7 psia

S_1 = 0, 0.2, 0.5, 0.85, 0.95

S_2 = 1.00

P_H° = 5.87 psia

P_V = 15.675 psia (27 inches of H_2O)

S_1^* = 0.1661, 0.3661, 0.6661, 1.00

S_2^* = 1.00

Results are shown on the following page in Table B-1 taken from Reference 1. Calculated losses ranged from 0.0066 to 0.1717 gm/gal (0.015 - 0.379 lb/10^3 gal; 0.002 - 0.045 kg/10^3 liters) for the open vent situation, and from 0 to 0.1538 gm/gal (0 - 0.339 lb/10^3 gal; 0 - 0.041 kg/10^3 liters) for the vent valve situation.

The above calculations are based on the assumption that the tank leaks at a rate sufficient to dissipate all tank pressure during the course of a trip. Some calculations were done using information on typical leak rates available at the time,[2] which indicated that pressure within exceptionally tight tanks may not be dissipated in a 60 minute trip, although it usually is.

2.2 TRANSIST WITH VAPOR LOADS (RETURN TRIP)[1]

Theoretical values for maximum emissions were calculated by assuming that the residual fuel present in the tank after the load is delivered vaporizes immediately and so causes vapor venting from the tank at the highest initial tank pressure. The amount of vapor lost depends on the rate of leakage of the tank, which in turn determines the residual pressure in the tank when it reaches the refueling terminal. For trips of sufficient duration to permit maximum dissipation of pressure, venting losses can be calculated using the same equations that were applied to the full load case described in Section 2.1. Since no experimental data base was available, a series of values was used for each parameter in an effort to cover the entire range of reasonable values.

TABLE B.1 VENT LOSS AFTER REFUELING

		OPEN VENT CALCULATION				
P = 14.7	S_1 =	0.	.2	.5	.85	.95
	V_V/V_G	.5097	.4265	.2870	.0951	.0327
GM/GAL VENTED	$V_G/V_L = 0.05$	.0572	.0555	.0453	.0182	.0066
	$V_G/V_L = 0.10$	.1145	.1110	.0906	.0365	.0132
	$V_G/V_L = 0.15$	.1717	.1665	.1359	.0547	.0198
		IDEAL 27 IN. H_2O VENT CALCULATION				
P = 15.675	S_1^* =	.1661	.3661	.6661		
	V_V/V_G	.4050	.3217	.1822		
GM/GAL VENTED	$V_G/V_L = 0.05$	.0513	.0466	.0316		
	$V_G/V_L = 0.10$	.1025	.0933	.0633		
	$V_G/V_L = 0.15$	.1538	.1399	.0949		

$\frac{V_G}{V_L}$ = 1.05, 1.10, 1.15

P = 14.7 psia

S_1 = 0, 0.3261, 0.7065, 0.8152

S_2 = 0.200, 0.500, 0.850, 0.950

P_H° = 5.87 psia

P_v = 15.675 psia (27 inches of H_2O)

S_1^* = 0.1661, 0.4922, 0.8726, 0.9813

S_2^* = 0.2055, 0.5265, 0.9099, 1.000

Results are shown on the following page in Table B-2 taken from Reference 1. Venting losses ranged from 0.037 to 0.350 gm/gal (0.082 - 0.772 $lb/10^3$ gal; 0.010 - 0.093 $kg/10^3$ liters) for the open vent situation, and from 0.013 to 0.067 gm/gal (0.029 - 0.148 $lb/10^3$ gal; 0.003 - 0.018 $kg/10^3$ liters) for the vent valve situation.

In situations where residual pressure still remains in the tank, losses can be calculated from the following equation:

$$\text{gm/gal transferred} = 4.142\ (S_2^*)\ \frac{(P_v - P_R)}{P_v}\ \frac{(V_G)}{V_L}$$

where symbols are as previously defined and

P_R = residual tank pressure, psia

The constant of 4.142 contains the assumption that P_H° = 5.87 psia, M_H = 66.7 lb m/lb mole, and T = 74.1°F.

Since no experimental measurements of P_R were available, calculations were made for a wide range of theoretically possible values. Using the following values, losses were calculated from the above equation:

TABLE B.2 VENT LOSS AFTER FUEL DROP

OPEN VENT LOSS					
P = 14.7	S_1 =	.0	.3261	.7065	.8152
	S_2 =	.2	.5000	.8500	.9500
	V_V/V_G =	.0832	.0832	.0832	.0832
GM/GAL VENTED	V_G/V_L = 1.05	.0367	.1499	.2820	.3197
	V_G/V_L = 1.10	.0385	.1571	.2954	.3350
	V_G/V_L = 1.15	.0402	.1642	.3088	.3502
IDEAL 27 IN. H_2O VENT LOSS					
	S_1 =	.0000	.3261	.7065	.8152
	S_1^* =	.1661	.4922	.8726	.9813
	S_2^* =	.2055	.5265	.9009	1.000
	V_V/V_G =	.0159	.0159	.0159	.0112
GM/GAL VENTED	V_G/V_L = 1.05	.0128	.0351	.0612	.0481
	V_G/V_L = 1.10	.0134	.0368	.0641	.0504
	V_G/V_L = 1.15	.0140	.0385	.0670	.0527

$S_2^* = 1.00, 0.9009, 0.5265, 0.2055$

P_v = 15.675 psia (27 inches of H_2O)

P_R = 20 different values ranging from 14.7 to 15.58 psia (0.0 to 21.6 inches of H_2O)

$\frac{V_G}{V_L} = 1.05, 1.10, 1.15$

Results are shown on the following page in Table B.7 taken from Reference 1. Losses ranged from 0.011 to 0.296 gm/gal (0.024 - 0.653 lb/10^3 gal; 0.0031 - 0.078 kg/10^3 liters).

3.0 MODIFIED CALCULATIONS BASED ON EXPERIMENTAL DATA[1, 3, 4]

The theoretical calculations above covered the entire range of values for most of the parameters for which no field measurements had been made (S_1, S_2, S_1^*, S_2^*, P_v, and P_R). Subsequently, experiments were conducted to determine where typical values lay within the range of values considered theoretically. Pressure measurements were made on tank trucks while they were filled with fuel and in transit. Pressures varied widely and frequently were negative because air, originally present in the vapor space, dissolved in the freshly charged fuel. This situation is apparently typical of fuel that has been stored in floating roof tanks and is not saturated with air.

In addition, vent valves were shown to open partially rather than fully at the valve opening pressure. Vapors in tanks were found to be somewhat less than saturated (71 to 96 percent) instead of 100 percent saturated, as originally assumed, when a value of 1.00 was chosen for S_2^* in the computations shown in Table B-1 from Reference 1. Moreover, truck leakage rates were shown to be

TABLE B.7 BLOWDOWN LOSS FOR VARIOUS FUEL DROP VENT SPACE AND TANK LEAKAGE SITUATIONS

		$S_2^* = 1.0$					
P_R IN. H_2O		0.0	1.54	6.69	15.23	20.72	
GM/GAL	VENTED $V_G/V_L = 1.05$	.2706	.2552	.2035	.1180	.0629	
	$V_G/V_L = 1.10$	.2835	.2673	.2132	.1236	.0659	
	$V_G/V_L = 1.15$	.2964	.2795	.2229	.1292	.0689	
		$S_2^* = .9009$					
ΔP_R IN. H_2O		0.0	1.8	7.12	15.35	20.75	
GM/GAL	VENTED $V_G/V_L = 1.05$	.2438	.2275	.1795	.1052	.0564	
	$V_G/V_L = 1.10$	.2554	.2384	.1880	.1102	.0591	
	$V_G/V_L = 1.15$	.2670	.2492	.1966	.1152	.0618	
		$S_2^* = .5265$					
ΔP_R IN. H_2O		0.0	2.2	7.2	15.7	21.0	
GM/GAL	VENTED $V_G/V_L = 1.05$	.1425	.1309	.1045	.0596	.0317	
	$V_G/V_L = 1.10$	.1492	.1371	.1094	.0625	.0332	
	$V_G/V_L = 1.15$	.1560	.1433	.1144	.0653	.0347	
		$S_2^* = .2055$					
ΔP_R IN H_2O		0.45	3.45	7.46	16.7	21.6	0.0
GM/GAL	VENTED $V_G/V_L = 1.05$	.0547	.0485	.0402	.0212	.0111	.0556
	$V_G/V_L = 1.10$	.0573	.0508	.0422	.0222	.0117	.0583
	$V_G/V_L = 1.15$	.0599	.0531	.0441	.0232	.0122	.0609

much lower than previously supposed--possibly as little as 5 percent of the rates used in the theoretical calculations.

Based on all these findings--specifically, a tank pressure (P_V) of 14.81 psia (3 inches of H_2O), leakage that persisted for 5 minutes before the tank pressure became negative, and a leak rate of 5 percent of that used previously--the authors of Reference 3 estimated that losses from transit with full loads are 0 - 0.035 gm/gal (0 - 0.077 lb/10^3 gal; 0 - 0.009 kg/10^3 liters) rather than the 0 - 0.0172 gm/gal that was computed theoretically. These calculations were performed using a computer program that employs the same fundamental equations given in Sections 2.1 and 2.2 and also considers leakage rates expressed as equivalent orifice diameters. A complete explanation is given in References 1 and 3. A summary of the results is shown in Table 1, taken from a June 10, 1977 letter from R.A. Nichols to H.B.Uhlig of Chevron USA, Inc., San Francisco, California.[4]

Experimental tests showed that the degree of saturation of vapors in empty tankers returning to be refilled was lower than previously estimated. A value for S_2^* of 0.10 was selected by the authors of Reference 3 as more representative than the values used in the theoretical calculations. The lower tank leakage rates also reduced the losses as compared with the original estimates. A range of values from 0 to 0.166 gm/gal (0 - 0.366 lb/10^3 gal; 0 - 0.044 kg/10^3 liters) was selected rather than the 0.011 - 0.350 gm/gal estimated from the theoretical analysis.

No experiments have been attempted for the purpose of monitoring the actual hydrocarbon emissions from tank trucks as they are in transit. The losses are so small that they could not be detected by weighing (or otherwise measuring) the load at the start and end of each run. Experiments have been designed to provide values for the various parameters used to compute losses from well established theoretical principles, however.

Table 1. TRUCK TRANSIT AND TRANSFER LEAKAGE LOSS

ΔP Loss In. H_2O	Leak Dia 5000 Gal In. O	Terminal Loss Gm/Gal	Terminal Vapor Vol%Loss	Liquid Trans. Loss Gm/Gal	Vapor Trans. Loss Gm/Gal	Loss S.S. Stage I Gm/Gal	S.S. Stage I Vol%Loss	TotLoss w/oStg I Gm/Gal	TotLoss w/stg I Gm/Gal.
0	0	0	0	0	0	.0911	2.20	0	.0911
0.5	.0528	.0002	.0037	.0001	.0016	.0915	2.21	.0019	.0934
1	.0749	.0003	.0076	.0002	.0032	.0924	2.23	.0037	.0961
2	.107	.0006	.0155	.0004	.0065	.0961	2.32	.0075	.1036
3	.131	.0010	.0232	.0006	.0097	.0994	2.40	.0113	.1107
4	.153	.0013	.0316	.0008	.0132	.1019	2.46	.0153	.1172
	.200	.0022	.0537	.0013	.0226	.1110	2.68	.0261	.1371
	.250	.0035	.0840	.0021	.0354	.1267	3.06	.0410	.1677
	.300	.0050	.1210	.0030	.0509	.1400	3.38	.0589	.1989
	.400	.0089	.2150	.0053	(.0828 .0905)	.1802	4.35	(.0970 .1047)	(.2772 .2849)
	.500	.0139	.3358	.0083	(.0828 .1415)	.2278	5.50	(.1051 .1637)	(.3328 .3915)
		ΔP = 6" Q_L =600gpm		ΔP=3"H_2O t=5min Max*=.0351	ΔP=6"H_2O t=60 min Max*=.0828 .1657				

* Leakage rate is such that maximum losses occur.

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1. Nichols, R.A., "Analytical Calculation of Fuel Transit Breathing Loss." Prepared by R.A. Nichols Engineering, Corona del Mar, Ca., for Chevron USA, Inc., San Francisco, Ca., March 21, 1977.

2. California Air Resources Board (CARB), "Delivery Tank Field Results." Attachment 2 to Staff Report 77-5-1, March 15, 1977.

3. Nichols, R.A., "Tank Truck Leakage Measurements." Prepared by R.A. Nichols Engineering, Corona del Mar, Ca., for Chevron USA, Inc., San Francisco, Ca., June 7, 1977.

4. Private correspondence from R.A. Nichols of R.A. Nichols Engineering, Corona del Mar, Ca., to H.B. Uhlig of Chevron USA, Inc., San Francisco, Ca., June 10, 1977.

4.5 WASTE SOLVENT RECLAMATION

4.5.1 Process Description[1-4]

Waste solvents are organic dissolving agents that are contaminated with suspended and dissolved solids, organics, water, other solvents, and/or any substance not added to the solvent during its manufacture. Reclaiming is the process of restoring a waste solvent to a condition that permits its reuse, either for its original purpose or for different industrial needs. The limiting factor that determines whether a solvent is reclaimed is economic because the cost of reclamation may exceed the value of the recovered solvent.

Industries that produce waste solvents include solvent refining, polymerization processes, vegetable oil extraction, metallurgical operations, pharmaceutical manufacture, surface coating, and cleaning operations (dry cleaning and solvent degreasing). The amount of solvent recovered from the waste solvent varies from about 40 to 99 percent, depending on the extent and characterization of the contamination and on the recovery process employed.

Design parameters and economic factors determine whether solvent reclamation is accomplished as a main process by a private contractor, as an integral part of a main process (such as solvent refining), or as an add-on process (as in the surface coating and cleaning industries). Most contract solvent reprocessing operations recover halogenated hydrocarbons (e.g., methylene chloride, trichlorotrifluoroethane, and trichloroethylene) from degreasing, and/or aliphatic, aromatic, and naphthenic solvents such as those used in the paint and coatings industry. They may also reclaim small quantities of numerous specialty solvents such as phenols, nitriles, and oils.

The general reclamation scheme for solvent reuse is illustrated in Figure 4.5-1. Industrial operations are, however, capable of reclaiming their waste solvent without incorporating all of these steps. For instance, initial treatment is only necessary when liquid waste solvents contain dissolved contaminants.

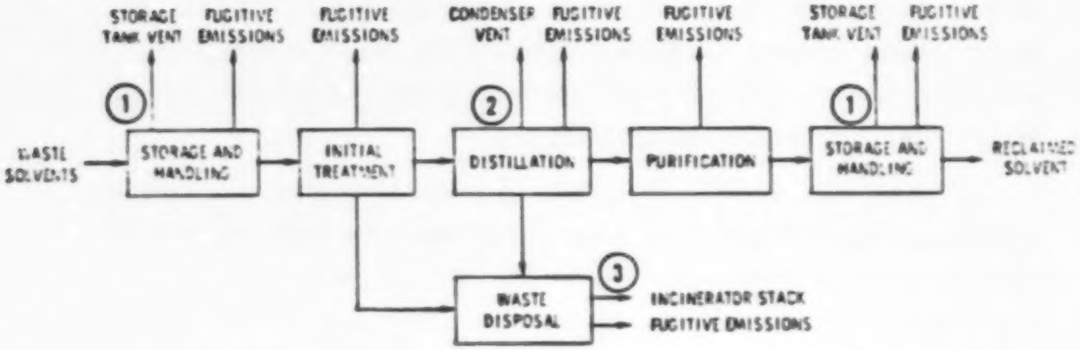
STORAGE TANK VENT
FUGITIVE EMISSIONS
FUGITIVE EMISSIONS
CONDENSER VENT
FUGITIVE EMISSIONS
FUGITIVE EMISSIONS
STORAGE TANK VENT
FUGITIVE EMISSIONS
①
②
①
WASTE SOLVENTS
STORAGE AND HANDLING
INITIAL TREATMENT
DISTILLATION
PURIFICATION
STORAGE AND HANDLING
RECLAIMED SOLVENT
③
WASTE DISPOSAL
INCINERATOR STACK
FUGITIVE EMISSIONS

Figure 4.5-1. General Waste Solvent Reclamation Scheme and Emission Points[1]

Solvent Storage and Handling - Solvents are stored before and after reclamation in containers ranging in size from 0.2 m^3 (55 gal) drums to tanks with capacities of 75 m^3 (20,000 gal) or more. Storage tanks are of fixed or floating roof design. Venting systems prevent solvent vapors from creating excessive pressure or vacuum inside fixed roof tanks.

Handling includes loading waste solvent into process equipment and filling drums and tanks prior to transport and storage. The filling is most often done through submerged or bottom loading.

Initial Treatment - Waste solvents are initially treated by vapor recovery or mechanical separation. Vapor recovery entails removal of solvent vapors from a gas stream in preparation for further reclaiming operations; in mechanical separation, undissolved solid contaminants are removed from liquid solvents.

Vapor recovery or collection methods employed include condensation, adsorption, and absorption. Technical feasibility of the method chosen depends on solvent miscibility, vapor composition, and vapor concentration; solvent boiling point, reactivity, and solubility; and several other factors.

Condensation of solvent vapors is accomplished by water-cooled condensers and refrigeration units. For adequate recovery, a solvent vapor concentration well above 20 mg/m^3 is required. To avoid explosive mixtures of a flammable solvent and air in the process gas stream, air is replaced with an inert gas, such as nitrogen. Solvent vapors that escape condensation are recycled through the main process stream or recovered by adsorption or absorption.

Activated carbon adsorption is the most common method of capturing solvent emissions. Adsorption systems are capable of recovering solvent vapors in concentrations below 4 mg/m^3 of air. Solvents with boiling points of 200°C (392°F) or more do not desorb effectively with the low pressure steam commonly used to regenerate the carbon beds. Figure 4.5-2 shows a flow diagram of a typical fixed-bed activated carbon solvent rcovery system. The mixture of steam and solvent vapor passes to a water-cooled condenser. Water immiscible solvents are simply decanted to separate the solvent, whereas water-miscible solvents must be distilled and solvent mixtures must be both decanted and distilled. Fluidized-bed operations are also in use.

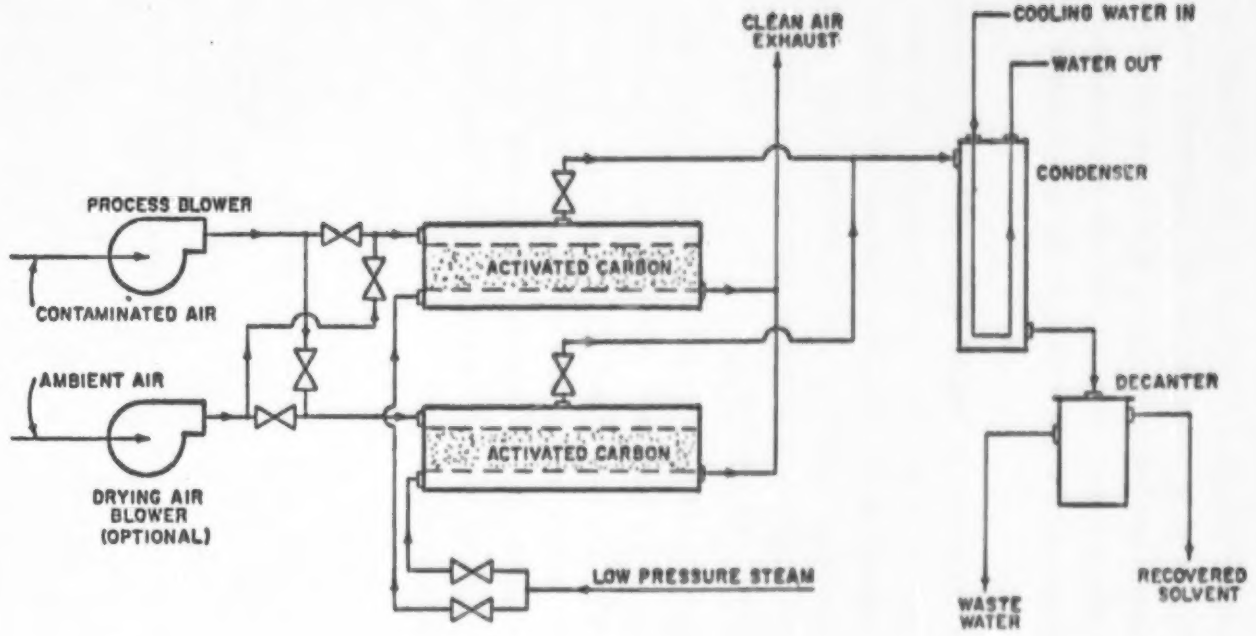
PROCESS BLOWER
CONTAMINATED AIR
AMBIENT AIR
DRYING AIR BLOWER (OPTIONAL)
ACTIVATED CARBON
ACTIVATED CARBON
LOW PRESSURE STEAM
CLEAN AIR EXHAUST
COOLING WATER IN
WATER OUT
CONDENSER
DECANTER
WASTE WATER
RECOVERED SOLVENT

Figure 4.5-2. Typical Fixed-Bed Activated Carbon Solvent Recovery System[6]

Absorption of solvent vapors is accomplished by passing the waste gas stream through a liquid in scrubbing towers or spray chambers. Recovery by condensation and adsorption results in a mixture of water and liquid solvent, while absorption results in an oil and solvent mixture. Further reclaiming procedures are required after solvent vapors are collected by any of these three methods.

Initial treatment of liquid waste solvents is accomplished by mechanical separation methods. This includes both removing water by means of decanting and removing undissolved solids by means of filtering, draining, settling, and/or centrifuging. A combination of initial treatment methods may be necessary to prepare waste solvents for further processing.

Distillation - After initial treatment, waste solvents are distilled to remove dissolved impurities and to separate solvent mixtures. Separation of dissolved impurities is accomplished by simple batch, simple continuous, or steam distillation. Mixed solvents are separated by multiple, simple distillation methods such as batch or continuous rectification. These processes are shown in Figure 4.5-3.

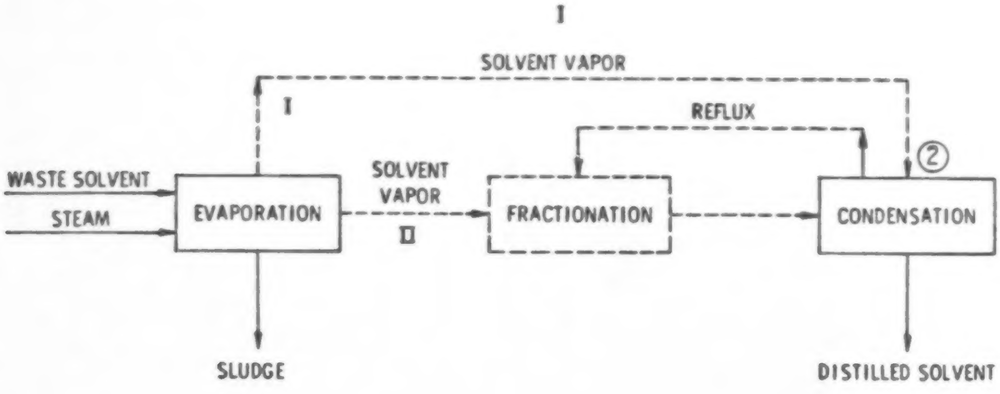

Figure 4.5-3. Distillation Process for Solvent Reclaiming[1]

In simple distillation, waste solvent is charged to an evaporator; vapors are then continuously removed and condensed, and the resulting sludge or still bottoms are drawn off. In steam distillation, solvents are vaporized by direct contact with steam which is injected into the evaporator. Simple batch, continuous, and steam distillations follow path I in Figure 4.5-3.

The separation of mixed solvents requires multiple simple distillations or rectification. Batch and continuous rectification are represented by path II in Figure 4.5.3. In batch rectification, solvent vapors pass through a fractionating column where they contact condensed solvent (reflux) entering at the top of the column; solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column; the more volatile solvents are drawn off at the top, while those with higher boiling points collect at the bottom.

Design criteria for evaporating vessels depend on waste solvent composition; scraped-surface stills or agitated thin-film evaporators are the most suitable for heat sensitive or viscous materials. Condensation is accomplished by shell and tube or barometric condensers. Azeotropic solvent mixtures are separated by the addition of a third solvent component, while solvents with higher boiling points, e.g., in the range of high flash naphthas (155°C, 311°F), are most effectively distilled under vacuum. Purity requirements for the reclaimed solvent determine the number of distillations, reflux ratios, and processing time needed.

Purification - After distillation, water is removed from solvent be decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent-water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed where water is removed by absorption.

During purification, reclaimed solvents are stabilized if necessary. Buffers are added to virgin solvents to ensure that pH is kept constant during use. Reclaiming the solvent may cause a loss of buffering capacity. To renew it, special additives are used during purification. The composition of these additives is considered proprietary.

Waste Disposal - Waste materials separated from solvents during initial treatment and distillation are disposed of by incineration, landfilling, or deep well injection. The composition of such waste varies depending on the original use of the solvent, but up to 50 percent is unreclaimed solvent, which keeps the waste viscous yet liquid, thus facilitating pumping and handling procedures. The remainder consists of components such as oils, greases, waxes, detergents, pigments, metal fines, dissolved metals, organics, vegetable fibers, and resins.

About 80 percent of the waste from solvent reclaiming by private contractors is disposed of in incinerators capable of burning liquid wastes. About 14 percent is deposited in sanitary landfills, usually in 55-gallon drums. Deep well injection consists of injecting wastes between impermeable geologic strata; viscous wastes may have to be diluted prior to pumping into the desired stratum level.

4.5.2 Emissions and Controls [1,3-5]

Volatile organic and particulate emissions result from waste solvent reclamation. Emission points include (1) storage tank vents, (2) condenser vents, (3) incinerator stacks, and fugitive losses (these numbers refer to Figures 4.5-1 and -3). Emission factors for these sources are given in Table 4.5-1 in kilograms of pollutant per metric ton and pounds per ton of reclaimed solvent.

Solvent storage results in volatile organic emissions from solvent evaporation (Figure 4.5-1, emission point 1). The condensation of solvent vapors during distillation (Figure 4.5-3) also involves VOC emisssions and, if steam ejectors are used, emission of steam and noncondensables as well (Figures 4.5-1 and -3, point 2). Incinerator stack emissions consist of solid contaminants that are oxidized and released as particulates, unburned organics, and combustion stack gases (Figure 4.5-1, point 3).

Volatile organic emissions from equipment leaks, open solvent sources (sludge draw-off and storage from distillation and initial treatment operations), solvent loading, and solvent spills are classified as fugitive; the former two sources are continuously released while the latter two are intermittently emitted.

Solvent reclamation is viewed by industry as a form of control in itself. It is estimated that less than 50 percent of reclamation plants run by private contractors utilize any control technology. Carbon adsorption systems can remove up to 95 percent of the solvent vapors from the air stream.

Volatile organic emissions from the storage of solvents can be reduced by as much as 98 percent by converting from fixed to floating roof tanks, although the percent reduction also depends on solvent evaporation rate, ambient temperature, loading rate, and tank capacity. Tanks may also be refrigerated or equipped with conservation vents, which prevent air inflow and vapor escape until some preset vacuum or pressure develops.

Solvent vapors vented during distillation are controlled by scrubbers and condensers. Direct flame and catalytic afterburners can also be used to control noncondensables and solvent vapors not condensed during distillation; the time required for complete com-

Table 4.5-1. EMISSION FACTORS FOR SOLVENT RECLAIMING[a]
EMISSION FACTOR RATING: D

Source	Criteria Pollutant	Emission Factor Range		Emission Factor Average	
		kg/MT	lb/ton	kg/MT	lb/ton
Storage tank vent[b]	Volatile organics	.002-.04	.004-.09	.0072	.0175
Condenser vent	Volatile organics	.26-4.17	.63-10.13	1.65	4.01
Incinerator stack	Volatile organics	.01	.02	.01	.02
Incinerator stack	Particulates	.55-1.0	1.34-2.43	.72	1.75
Fugitive emissions					
Spillage	Volatile organics[c]	.095	.23	.095	.23
Loading	Volatile organics	.00012-.71	.00029-1.72	.36	.875
Leaks	Volatile organics	d	d	d	d
Open sources	Volatile organics	d	d	d	d
TOTAL	Volatile organics	.38-5.0	.92-12.15	2.1	5.10
TOTAL	Particulates	.55-1.0	1.34-2.43	.72	1.75

[a] Data obtained by Reference 1 from state air pollution control agencies and presurvey sampling. All emission factors are for uncontrolled process equipment except those for the incinerator stack. (Reference 1 does not, however, specify what the control is on this stack.)

[b] Storage tank is of fixed roof design.

[c] Only one value available.

[d] Not available.

bustion depends on the flammability of the solvent. Carbon or oil adsorption may be employed as well, as in the case of vent gases from the manufacture of vegetable oils.

Wet scrubbers are used to remove particulates from sludge incinerator exhaust gases, although they do not effectively control submicron-sized particles.

Submerged rather than splash filling of storage tanks and tank cars can reduce solvent emissions from this source by more than 50 percent. Proper plant maintenance and loading procedures reduce emissions from leaks and spills. Open solvent sources can be covered to reduce these fugitive emissions.

References for Section 4.5

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5. Meyer, W.R., "Solvent Broke." Vulcan-Cincinnati, Inc., Cincinnati, Ohio. Proceedings of TAPPI Testing Paper Synthetics Conference, Boston, Mass., October 7-9, 1974, pp. 109-115

6. Shaw, Nathan R., "Vapor Adsorption Technology for Recovery of Chlorinated Hydrocarbons and Other Solvents." Preprint of Paper Presented at the 80th Annual Meeting of the Air Pollution Control Association, Boston, Massachusetts, Paper 75-123: June 15-20, 1975

BACKGROUND DOCUMENT

SECTION 4.5 WASTE SOLVENT RECLAMATION

The only available document that lists emission factors for waste solvent reclamation is Monsanto Research Corporation's Source Assessment: Reclaiming of Waste Solvents - State of the Art (Reference 1). Accordingly, Table 4.5-1 of Section 4.5 is adapted from Table 6 of this reference.

Footnote a of Table 4.5-1 states that the data in this table were obtained "from state air pollution control agencies and presurvey sampling." These agencies are not documented elsewhere in Reference 1. Appendix B of Reference 1 is entitled "Results and Sample Calculations for Presurvey Sampling of Private Contractor Solvent Reclaiming Plant," but neither the storage tank vent nor the condenser vent emission factors calculated therein correspond to the factors published in Table 6 of the report and reproduced in Table 4.5-1 of AP-42 Section 4.5.

It is possible that the information given in Appendix B of Reference 1 does pertain to the emission factors that appear in Table 6 of the same reference (i.e., Table 4.5-1 of AP-42 Section 4.5). However, if this is the case, the authors of Reference 1 have not made the connection clear.

The control efficiencies mentioned in Section 4.5.2 are given in the references cited, which in no case provide background data for these percentages.

The amount of source test data is not specified in Reference 1. The process is highly variable and depends on the particular solvent and recovery scheme used. The data on which material balance calculations could be based is also not specified in Reference 1. For these reasons the rating of D was assigned to all emission factors in Table 4.5-1.

4.6 SOLVENT DEGREASING

4.6.1 Process Description[1,2]

Solvent degreasing (or solvent cleaning) is the physical process of removing grease, fats, oils, wax, or soil from various metal, glass, and plastic items with organic solvents. The types of equipment used in this method are categorized as cold cleaners, open top vapor degreasers, or conveyorized degreasers. Nonaqueous solvents such as petroleum distillates, chlorinated hydrocarbons, ketones, and alcohol are used. Solvent selection is based on the solubility of the soil and the toxicity, flammability, flash point, evaporation rate, boiling point, cost, and several other properties of the solvent.

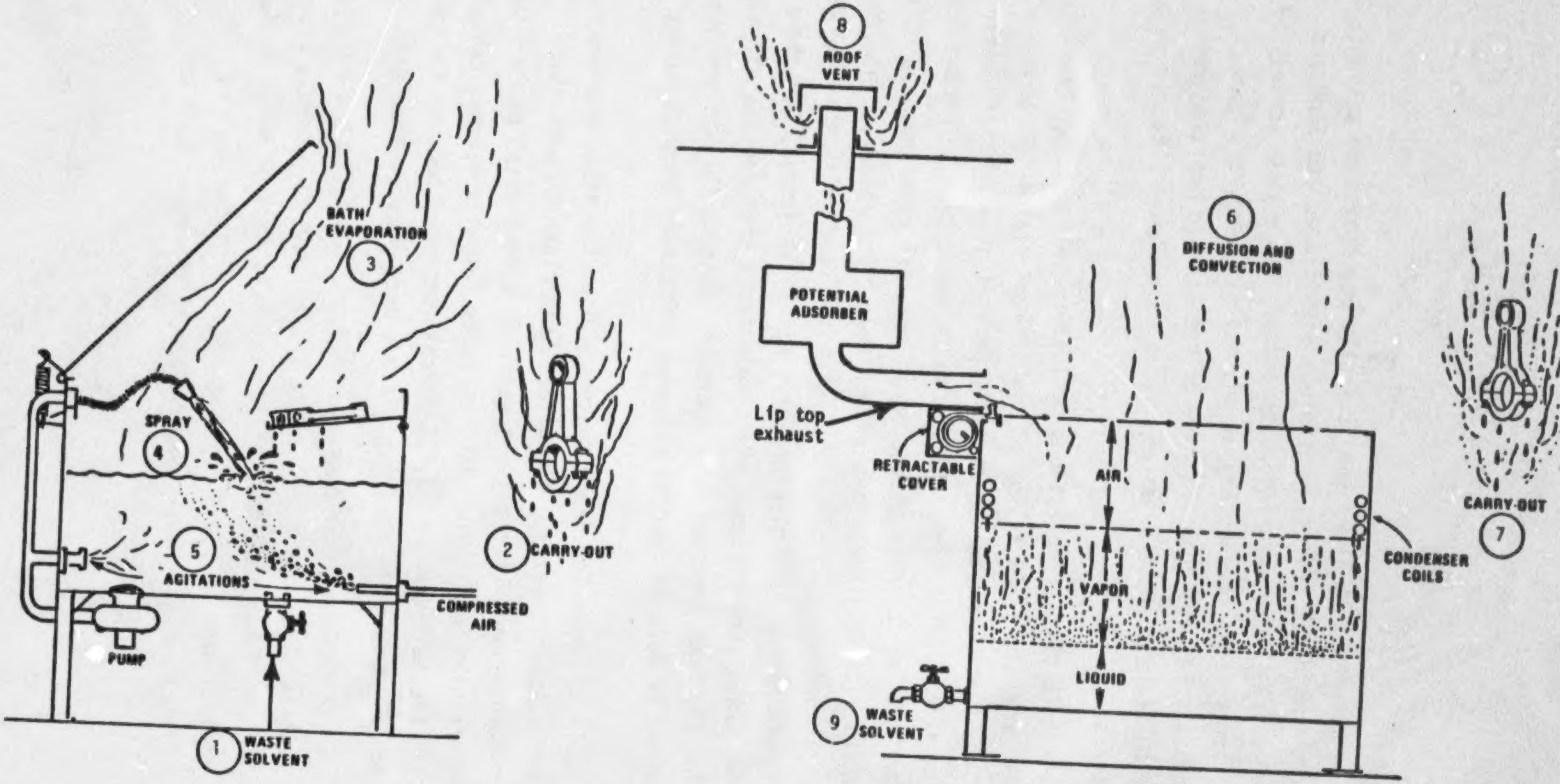
The metal working industry is the major user of solvent degreasing; examples are the automotive, electronics, plumbing, aircraft, refrigeration, and business machine industries. Solvent cleaning is also used in industries such as printing, chemicals, plastics, rubber, textiles, glass, paper, and electric power. Most transportation vehicle and electric tool repair stations utilize solvent cleaning at least part of the time. Many industries also use water-based alkaline wash systems for degreasing. These systems emit no solvent vapors to the atmosphere and are therefore not included in this discussion.

4.6.1.1 Cold Cleaners - Cold cleaners are batch loaded, non-boiling solvent degreasers, and are usually the simplest, least expensive method of metal cleaning. The two basic types are maintenance and manufacturing. Maintenance cold cleaners are more numerous, smaller, and generally use petroleum solvents such as mineral spirits (petroleum distillates and Stoddard solvents). Manufacturing cold cleaners use a wide variety of solvents; they perform higher quality cleaning, are more specialized, and have about twice the average emission rate of maintenance cold cleaners. Some cold cleaners can serve both purposes.

Cold cleaner operations include spraying, brushing, flushing, and immersion. In a typical maintenance cleaner (Figure 4.6-1), dirty parts are cleaned manually by spraying and then soaking in the tank. After cleaning, the parts are either suspended over the tank to drain or placed on an external rack that routes the drained solvent back into the cleaner. The cover is intended to be closed whenever parts are not being handled in the cleaner. Manufacturing cold cleaners vary widely in design, but there are two basic tank designs: the simple spray sink and the dip tank. The dip tank provides more thorough cleaning through soaking and often is made to improve cleaning efficiency through agitation.

4.6.1.2 Open Top Vapor Systems - Open top vapor degreasers are batch loaded, boiling degreasers that clean through the condensation of hot solvent vapor on colder metal parts. Vapor degreasing uses halogenated solvents (usually perchloroethylene, trichloroethylene, or 1,1,1-trichloroethane) because they are not flammable and their vapors are much heavier than air.

A typical vapor degreaser (Figure 4.6-1) is a sump containing a heater that boils the solvent to generate vapors. The upper level of these pure vapors is controlled by condenser coils and/or by a water jacket encircling the device. A "freeboard" extends above the top of the vapor zone to


BATH/ EVAPORATION
3
SPRAY
4
5
AGITATIONS
PUMP
2 CARRY-OUT
COMPRESSED AIR
1 WASTE SOLVENT
8
ROOF VENT
POTENTIAL ADSORBER
6
DIFFUSION AND CONVECTION
Lip top exhaust
RETRACTABLE COVER
AIR
VAPOR
LIQUID
CONDENSER COILS
7
CARRY-OUT
9 WASTE SOLVENT

Cold cleaner

Open top vapor degreaser

Figure 4.6-1. Degreaser Emission Points

minimize vapor escape. Parts to be cleaned are immersed in the vapor zone; condensation continues until they are heated to the vapor temperature. Residual liquid solvent on the parts rapidly evaporates as they are slowly removed from the vapor zone. Cleaning action is often increased by spraying the parts with solvent (below the vapor level) or by immersing them into the liquid solvent bath. Nearly all vapor degreasers are equipped with a water separator which allows the solvent to flow back into the degreaser; many also have lip-mounted exhaust systems which capture solvent vapors and carry them away from operating personnel.

4.6.1.3 Conveyorized Degreasers - Conveyorized degreasers may operate with either cold or vaporized solvent, but merit separate consideration because they are continuously loaded and almost always hooded or enclosed. About 85 percent are vapor types and 15 percent are nonboiling.

4.6.2 Emissions and Controls[1,2,3]

Emissions from cold cleaners occur through (1) waste solvent evaporation, (2) solvent carry-out (evaporation from wet parts), (3) solvent bath evaporation, (4) spray evaporation, and (5) agitation (Figure 4.6-1). Waste solvent loss, cold cleaning's greatest emission source, can be minimized through distillation and special incineration plants; draining cleaned parts for at least 15 seconds reduces carry-out emissions. Bath evaporation can be controlled by regularly using a cover, allowing an adequate freeboard height, and avoiding excessive drafts in the workshop. If the solvent used is insoluble in and heavier than water, a layer of water about two to four inches thick covering the halogenated solvent can also reduce bath evaporation. This is known as a "water cover." Spraying at low pressure helps reduce solvent loss from this part of the process. Agitation emissions can be controlled through use of a cover, agitating no longer than necessary, and avoiding the use of agitation with low volatility solvents. Emissions of low volatility solvents increase significantly with agitation; however, contrary to what one might expect, agitation causes only a small increase in emissions of high volatility solvents. Solvent type, particularly its volatility at the operating temperature, is the variable which most affects cold cleaner emission rates.

As with cold cleaning, open top vapor degreasing emissions depend heavily on proper operating methods. Most emissions are due to (6) diffusion and convection, which can be minimized by using an automated cover, regularly using a manual cover, spraying below the vapor level, optimizing work loads, or using a refrigerated freeboard chiller (for which a carbon adsorption unit would be substituted on larger units). Safety switches and thermostats that prevent emissions during malfunctions and abnormal operation also reduce diffusion and convection from the vaporized solvent. Additional sources are (7) solvent carry-out, (8) exhaust systems, and (9) waste solvent evaporation (Figure 4.6-1). Carry-out is directly affected by the size and shape of the workload, racking of parts, and cleaning and drying time. Exhaust emissions can be nearly eliminated by a carbon adsorber that collects the waste solvent for reuse. Waste solvent evaporation is not as much of a problem with vapor degreasers as it is for cold cleaners because the halogenated solvents used are often distilled and recycled by solvent recovery systems.

Because of their large workload capacity and the fact that they are usually enclosed, conveyorized degreasers emit less solvent per part cleaned than either of the other two types of degreaser. Compared to operating practices, design and adjustment are major factors affecting emissions, the main source of which is carry-out of vapor and liquid solvent.

Emission rates are usually estimated from solvent consumption data for the particular degreasing operation under consideration. Solvents are often purchased specifically for use in degreasing and are not used in any other plant operations; in these cases, purchase records provide the necessary information and an emission factor of 1,000 kg of volatile organic emissions per metric ton of solvent can be applied (Table 4.6-1). This factor is based on the assumption that solvent consumption equals emissions. When information on solvent consumption is not available, emission rates can be estimated if the number and type of degreasing units are known. The factors in Table 4.6-1 are based on the number of degreasers and emissions produced nationwide and therefore may be considerably in error when applied to one particular unit.

The expected effectiveness of various control devices and procedures are listed in Table 4.6-2. As a first approximation, these efficiencies can be applied without regard for the specific solvent being used; however, efficiencies are generally higher for more volatile solvents. These solvents also result in higher emission rates than those computed from the "average" factors listed in Table 4.6-1.

References for Section 4.6

1. Marn, P.J.; Hoogheem, T.J.; Horn, D.A.; and Hughes, T.W. Source Assessment: Solvent Evaporation-Degreasing. Draft document. Monsanto Research Corporation, Dayton, Ohio. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, under Contract No. 68-02-1874, January, 1977.

2. Control of Volatile Organic Emissions from Solvent Metal Cleaning. EPA-450/2-77-022 (OAPQS No. 1.2-079). U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, November 1977.

3. Suprenant, K.S. and Richards, D.W. Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Final and Appendix Reports. Dow Chemical Company, Midland, Mich. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, under Contract No. 68-02-1329, Task No. 9, June 30, 1976.

Table 4.6-1. SOLVENT LOSS EMISSION FACTORS FOR DEGREASING OPERATIONS
EMISSION FACTOR RATING: C

Type of degreasing	Activity measure	Uncontrolled organic emission factor[a]	
All[b]	Solvent consumed	2,000 lb/ton	1,000 kg/MT
Cold cleaner			
Entire unit[c]	Units in operation	0.33 tons/yr·unit	0.30 MT/yr·unit
Waste solvent loss		0.18 tons/yr·unit	0.165 MT/yr·unit
Solvent carryout		0.08 tons/yr·unit	0.075 MT/yr·unit
Bath and spray evaporation		0.07 tons/yr·unit	0.060 MT/yr·unit
Entire unit	Surface area and duty cycle	0.08 lb/hr. ft^2	0.4 kg/hr. m^2 [d]
Open top vapor			
Entire unit	Units in operation	10.5 tons/yr·unit	9.5 MT/yr·unit
Entire unit	Surface area and duty cycle	0.15 lb/hr· ft^2	0.7 kg/hr·m^2 [e]
Conveyorized, vapor			
Entire unit	Units in operation	26 tons/yr·unit	24 MT/yr·unit
Conveyorized, nonboiling			
Entire unit	Units in operation	52 tons/yr·unit	47 MT/yr·unit

[a] 100 percent nonmethane hydrocarbons or volatile organic compounds.

[b] Solvent consumptionn data will provide much more accurate emission estimates than any of the other factors presented.

[c] Emissions would generally be higher for manufacturing units and lower for maintenance units.

[d] For trichloroethane degreaser. From Reference 3, Appendix C-6.

[e] For trichloroethane degreaser. Does not include waste solvent losses.

Table 4.6-2. PROJECTED EMISSION REDUCTION FACTORS FOR SOLVENT DEGREASING[a]

	System Scenario					
	Cold Cleaner		Vapor Degreaser		Conveyorized Degreaser	
System	A	B	C	D	E	F
Control Devices						
cover or enclosed design	X	X	X	X	X	X
drainage facility	X	X	X			X
water cover, refrigerated chiller, carbon adsorption or high freeboard[b]		X		X		X
solid, fluid spray stream[c]						
safety switches and thermostats				X		X
emission reduction from control devices	13-38	NA[e]	20-40	30-60		40-60
Operating Procedures						
proper use of equipment	X	X	X	X	X	X
use of high volatility solvent		X				
waste solvent reclamation	X	X	X	X	X	X
reduced exhaust ventilation			X	X	X	X
reduced conveyer or entry speed			X	X	X	X
emission reduction from operating procedures	15-45	NA[e]	15-35	20-40	20-30	20-30
Total Emission Reduction (percentage)	28-83[d]	55-69[f]	30-60	45-75	20-30	50-70

[a] Reference 2. Ranges of emission reduction represent poor to excellent compliance.

[b] Only one of these major control devices would be used in any degreasing system. System B could employ any of them; system D could employ any except water cover; system F could employ any except water cover and high freeboard.

[c] If agitation by spraying is used, the spray should not be a shower type spray.

[d] A manual or mechanically assisted cover would contribute 6-18% reduction; draining parts 15 seconds within the degreaser, 7-20%; and storing waste solvent in containers, an additional 15-45%.

[e] Breakdown between control equipment and operating procedures is not available.

[f] Percentages represent average compliance.

BACKGROUND DOCUMENT
SECTION 4.6 SOLVENT DEGREASING

1.0 INTRODUCTION

The information on emissions from solvent degreasing was developed from (1) telephone surveys of responsible persons in industries engaged in degreasing, and (2) a series of studies carried out under EPA sponsorship to evaluate various emission control devices. Information from both sources was used to compute emission factors. A detailed discussion of these computations follows.

2.0 FACTORS BASED ON SURVEY DATA

A nationwide survey of metal working industries was conducted by the Dow Chemical Company to obtain information on emissions from solvent degreasing (Reference 3, Appendix Report). Metal working industries employing 20 or more people were surveyed within the following industrial classifications:

- Furniture and fixtures
- Primary metal industries
- Fabricated metal products
- Machinery (except electrical)
- Electrical and electronic equipment
- Transportation equipment
- Instruments and related products
- Miscellaneous manufacturing industries

A representative sample of 2,578 out of a possible 41,670 plants was surveyed by telephone to ascertain the types of degreasers employed, the specific solvents used, and the quantities consumed and disposed of by various routes. The results of this survey were as follows:

● Number of maintenance cold cleaners in the U.S. in 1974	880,000
● Number of manufacturing cold cleaners	340,000
● Number of open top vapor degreasers	21,000
● Number of conveyorized vapor degreasers	3,170
● Number of conveyorized nonboiling degreasers	530

The estimates of solvent usage from the survey were compared with similar estimates from other surveys (Table 1), and a weighted average solvent consumption for each type of degreaser was computed.

2.1 COLD CLEANING

Of the 450×10^3 MT/yr of solvents consumed in cold cleaning, 25×10^3 MT/yr are used in wiping operations, which are not considered cold cleaner emissions, and another 25×10^3 MT/yr are used in conveyorized nonboiling degreasers, which are considered separately. Another 20×10^3 MT/yr are incinerated or landfilled after use in such a manner that no emissions occur. Thus, 380×10^3 MT/yr of solvents find their way into the atmosphere as a result of cold cleaning operations. The average emissions per unit can be computed as

$$\frac{380 \times 10^3 \text{ MT/yr}}{\underset{\text{maintenance units}}{880{,}000} + \underset{\text{manufacturing units}}{340{,}000}} = \underset{\text{cold cleaning unit}}{0.31 \text{ MT/yr per}}$$

If it is assumed that manufacturing cold cleaners have twice the emission rate of maintenance cold cleaners, then by simple algebra manufacturing units average 0.48 MT/yr and maintenance units average 0.24 MT/yr. By using their best engineering judgement, the authors of Reference 2 estimated that 55 percent of cold cleaning emissions are due to waste solvent evaporation, 20 percent to bath and spray evaporation, and 25 percent to carryout losses. The emission factors for each part of the cold

Table 1. U.S. CONSUMPTION OF DEGREASING SOLVENTS[a] 1974 (10^3 metric tons/year)

Solvent Type	Weighted Average	Monsanto-S.A.D. Tom Hoogheem-1974	U.S. Tariff Comm. Report for 1974	Dow Final Report Survey for 1974	Dow Chart for 1974	Detrex 1975	Estimates Projected 1974	J.S. Gunnin Shell Chemical Solvent Bus. Ctr
	VD+CC=Total	VD + CC = Total	VD + CC = Total	VD + CC = Total	VD only	VD	VD	
Halogenated								
Trichloroethylene	128 + 25 = 153	157	142 + 8 = 150	103 + 39 = 142	143	114	124	No data
1,1,1 trichloroethane	80 + 82 = 162	90 + 78 = 168	73 +106 = 179	110 + 63 = 173	73	63	53	
Perchloroethylene	41 + 13 = 54	43 + 11 = 54	40 + 19 = 59	41 + 9 = 50	40	45	40	
Methylene chloride	7 + 23 = 30	10 + 46 = 56	7 + 18 = 25	7.5 +6.3 = 13.8	9	8	6	
Trichlorotrifluoroethane	20 + 10 = 30	- - 17	- - -	34 + 18 = 52	20	20	18	
Total	276 +153 = 429	-	-	296 +135 = 431	285	250	241	
Aliphatic	222	225						218
Aromatic								
Benzene	7	7	No data	No data	No data	No data	No data	
Toluene	14	14						-
Xylene	12	12						-
Cyclohexane	1	1						-
Heavy aromatics	12	-						12
Total	46	-						-
Oxygenated								
Ketones								
Acetone	10	10	No data	10	No data	No data		No data
Methyl ethyl ketone	8	7.5		8				
Alcohols								
Butyl	5	3.3		7				
Ethers	6	6		-				
Total	29	26.8		-				
TOTAL	726							

Breakdown:

Expected Accuracy:

Ranges:

Vapor deg. solvents = VD = 276≈275

±10 percent → VD = 275 ± 25 = 250 to 300 (x 10^3 metric ton/yr)

Cold clean. solvents = CC = 153 + 222 + 46 + 29
= 153 + 222 + 75
= 153 + 297
= 450

±15% ± 30% ± 50% → CC = (155 ± 25) + (220 ± 65) + (75 ± 35)
= (130 + 155 + 38) to (180 + 285 + 112)
= 323 to 557
= 450 + 127

[a] From Reference 2 (EPA 450/2-77-022)

cleaning process were derived by applying these percentages to the overall factor for the entire unit. Emission factors were not computed for individual solvent types, but represent composite factors for all solvents.

2.2 OPEN TOP VAPOR DEGREASING

According to Table 1, 275 x 10^3 MT/yr of solvents are used in vapor degreasing. Based on information from the survey and best engineering judgement, the authors of Reference 2 estimated that 75 x 10^3 MT/yr are from conveyorized vapor degreasing, and the remaining 200 x 10^3 MT/yr from open top vapor degreasing. The emissions per unit were computed as

$$\frac{200 \times 10^3 \text{ MT/yr}}{21{,}000 \text{ units}} = 9.5 \text{ MT/yr per open top vapor degreasing unit}$$

No attempt was made to separate this emission factor into subfactors that represent various parts of the vapor degreasing operation (as was done for cold cleaning).

2.3 CONVEYORIZED DEGREASING

Solvent usage in conveyorized nonboiling and vapor degreasing was estimated to be 25 x 10^3 MT/yr and 75 x 10^3 MT/yr, respectively (refer to Sections 2.1 and 2.2). Emission factors for each type of unit were computed as follows:

$$\frac{25 \times 10^3 \text{ MT/yr}}{530 \text{ nonboiling units}} = 47.2 \text{ MT/yr per conveyorized nonboiling unit}$$

$$\frac{75 \times 10^3 \text{ MT/yr}}{3{,}170 \text{ vapor units}} = 23.7 \text{ MT/yr per conveyorized vapor unit}$$

As in the previous cases, these factors apply to composite average units and solvent types.

3.0 FACTORS BASED ON TEST DATA

One study (Reference 3, Appendix C-6) was carried out on a Baron Blakeslee Model HD 425 vapor degreaser, which was operated both as a cold cleaner and as a vapor degreaser by the Prestolite Corporation at Bay City, Michigan, using 1,1,1 trichloroethane as the solvent. When used as a vapor degreaser for one year, the unit operated for 16 hours per day for 250 days and consumed 550 gallons (2,737 kg) of solvent. When used as a cold cleaner for 25 days at 16 hours per day, the unit consumer 18 gallons (90 kg). No waste solvent disposal was carried out during the 25 day test, so these losses are not included as they are in the 250 day test of vapor degreasing. These figures equate to 1.5 lb/hr for the vapor degreaser and 0.49 lb/hr for the cold cleaner. Waste solvent disposal was estimated to add 0.3 lb/hr for the cold cleaner.

The cleaner used for this test had a surface area of 10.2 ft^2 (.95 m^2), so the emissions were calculated to be 0.048 $lb/hr \cdot ft^2$ (.23 $kg/hr \cdot m^2$) for the cold cleaner without waste solvent disposal, and 0.077 $lb/hr \cdot ft^2$ (.37 $kg/hr \cdot m^2$) for the cold cleaner including the estimated emissions from waste solvent disposal. Emissions from the vapor degreasing test are calculated as 0.15 $lb/hr \cdot ft^2$ (.71 $kg/hr \cdot m^2$) for the entire operation. The factors listed in AP-42, Table 4.6-1 are based entirely on the Prestolite Corporation tests for the applications where activity measures were given in terms of the unit's surface area and duty cycle (Reference 3, Appendix C-6).

Evaporation rate tests were also conducted for two cold cleaners under a variety of operating conditions for periods of 16 to 164 hours, and loss rates of 0.006 to 0.59 $lb/hr \cdot ft^2$ (.003 to 2.8 $kg/hr \cdot m^2$) were measured (Reference 1, Appendix A-2). These tests illustrate the extreme range of emission rates that may be encountered; they did not define typical, real-world operation and therefore were not used in the development of emission factors.

4.0 EMISSION REDUCTION FACTORS

The authors of Reference 2 made the emission reduction factor estimates given in AP-42, Table 4.6-2 by combining their best engineering judgment and the results of the tests summarized in Table 2.

5.0 EMISSION FACTOR RATING

The conventional rating system gives the following weighting to the various information categories: measured emission data, 20 points maximum; process data, 10 points maximum; engineering analysis, 10 points maximum. In the case of solvent degreasing, where the most accurate estimate of emissions is based on a material balance, less importance was assigned to measured emission data because they do not appreciably increase the accuracy of an emissions estimate based on solvent consumption. The following rating system was used:

	Maximum Points	Solvent Degreasing
Measured emission data	10	4
Process data	10	6
Engineering analysis	20	15
TOTAL:	40	25

The emission factor rating for 25 points is C.

Table 2. TEST RESULTS FROM DOW REPORT[a]

Satisfactory Control Systems

Dow Report[b] Appendix No.	User	Degreaser[b]	Vapor Area	Solvent	Uncontrolled Emission Rate (gal/unit)	Uncontrolled Emission Rate (lb/ft².hr)	Controlled Emission (gal/unit)	Controlled Emission (lb/ft².hr)	Controlled Efficiency η%	Control System	Comments
C-5	Pratt & Whitney	OTVD	65 x 110 in. 49.6 ft²	1,1,1	97.5 gal/wk	0.16	50.4 gal/wk	0.10	48%	Cover-pneumatically powered	Uncovered for 24 hr/day and 7 day/wk
C-2	Eaton	OTVD	-	Tri. 1,1,1	129 lb/ton 111 lb/ton	- -	99 lb/ton 80 lb/ton		23% 28%	Cover (manual)	No much information on the test
C-12	Dow Lab	OTVD	24.2 x 22 in. 3.7 ft²	1,1,1		0.373 0.373 0.373		0.373 0.273 0.167	0 27% 55%	FR = 0.5 = 0.75 = 1.0	Idle (no work loads), moderate draft
			24.2 x 22 in. 3.7 ft²	1,1,1		0.955 0.955 0.955		- 0.051 0.054	- 48% 43%	FR = 0.5 0.75 1.0	Idle, quiet air
C-3	Hamilton Standard	OTVD (No. 203)	15 ft²	Methylene chloride	7.5 gal/opday 6.43 gal/day	0.186	4.53 gal/opday 3.67 gal/day	0.112	40%	Cold trap FR = 0.83 (covered during disuse)	Work load when CT on was 50% more than when CT off →η=40%
		OTVD (O&R)	11.1 ft²	Methylene chloride	3.63 gal/opday 2.9 gal/day	0.450	2.60 gal/opday 1.73 gal/day	0.322	28% 40%	Cold trap FR = 0.75 (never covered)	Inaccurate results. The O&R deg is expected to have a higher η, due to being uncovered. O&R had only ~3 work loads per operating day whereas No. 203 had 29 to 63 wkld/opday.
C-10	Vic	OTVD	12 x 4.5 ft. 54 ft²	Tri.	100 gal/wk	0.605	38 gal/wk	0.213	65%	Carbon adsorption	Ventilation rate of 103 cfm/ft². Accuracy of record-keeping is reported by Dow to be poor. Thus, accuracy of results would be poor
C-7	Schlage Lock	CVD-monorail	41.3 ft²	Perc.	19.6 gal/wday	0.79	7.5 gal/wday	0.304	62%	Chiller	Range of η is 45 to 65%
C-11	W. Electric Hawthorne	CMD defluxer	-	Tri.	0.083 gal/ft² of circuit board 23.0 gal/wday	-	0.025 gal/ft² 10.4 gal/wday	-			
Unsatisfactory Control Systems											
C-5	Pratt & Whitney	OTVD	56 x 90 in. 35 ft²	1,1,1	50 gal/wk	0.130	49 gal/wk	0.117	10%	Cold trap	FR = 50%, cold trap design tested here was reported as an obsolete model. Covered during disuse.
C-8	Super Radiator	OTVD	6 x 12 ft. 72 ft²	Perc.	49 gal/day	1.53	37 gal/day	1.14	-4%	Carbon adsorption	Defective adsorption system - breakthrough; insufficient FR≈0.04 ≤ FR 0.1. Only 37 cfm/ft²
C-4	Hewlett Packard	CMD monorail developer		1,1,1	0.33 gal/board		0.26 gal/board		21%	Carbon adsorption	Low control efficiency of the adsorption system is thought to be because of poor ventilation design
C-9	J.L. Thompson	CVD crossrod		Tri.	1.4 gal/hr		1.05 gal/hr		25%	Carbon adsorption	Material balance results
					90.5 gal/wk		69.5 gal/wk		30%	Carbon adsorption	Results from purchase records

Abbreviations: OTVD = Open Top Vapor Degreaser, CVD = Conveyorized Vapor Degreaser, CMD = Conveyorized Nonboiling Degreaser, Opday = Day degreaser is in operation, wday = working day, CT = Cold Trap, FR = Freeboard Ratio lb/ton = pounds of solvent emitted per ton of parts degreased, WKLD = work load, 1,1,1 = methyl chloroform, Tri. = trichloroethylene, Perc. = perchloroethylene.

[a] From Reference 2 (EPA 450/2-77-022)

[b] The appendix of the Dow Report describes each test in detail.

4.7 TANK AND DRUM CLEANING

4.7.1 Process Description

Rail tank cars, tank trucks, and drums are used to transport about 700 different commodities. The interiors of rail cars, and most tank trucks and drums, are in dedicated service (carrying one commodity only) and, unless contaminated, are cleaned only prior to repair or testing. Nondedicated tank trucks (about 20,000 or 22 percent of the total in service) and drums (approximately 5.6 million or 12.5 percent of the total) are cleaned after every trip.

4.7.1.1 Rail Tank Cars - Most rail tank cars are privately owned. Some of these, like railroad-owned cars, are operated on a for-hire basis. The commodities hauled (and cleaned) are 35 percent petroleum products (excluding gasoline, fuel oils, and lubricating oils), 20 percent organic chemicals, 25 percent inorganic chemicals, 15 percent compressed gases, and 5 percent food products.

Much tank car cleaning is conducted at shipping and receiving terminals, where the wastes go to the manufacturers' treatment systems. However, 30 to 40 percent is done at service stations operated by tank car owner-lessors. These installations clean out wastes derived from a wide variety of commodities, many of which require special cleaning methods.

A typical tank car cleaning facility cleans 4 to 10 cars per day. Capacity per car varies from 38 to 129 m^3 (10,000 to 34,000 gal). Cleaning agents include steam, water, detergents, and solvents, which are applied using steam hoses, pressure wands, or rotating spray heads placed through the opening in the top of the car. Scraping of hardened or crystallized products is often necessary. Cars carrying gases and volatile materials and those that are to be pressure tested must be filled or flushed with water. The average amount of residual material cleaned from each car is estimated to be 250 kg (550 lb). Vapors from cleaning cars that are not flared or dissolved in water are dissipated to the atmosphere.

4.7.1.2 Tank Trucks - Two thirds of the tank trucks in service in the United States are operated on a for-hire basis; of these, 80 percent are used to haul bulk liquids. Most companies operate fleets of five trucks or less; wherever possible, these trucks are consigned to dedicated service. Commodities hauled and cleaned are 15 percent petroleum products (excluding gasoline, fuel oils, and lubricating oils), 35 percent organic chemicals, 5 percent food products, and 10 percent other (paint, inks, naval stores, and so son).

Interior washing is carried out at many tank truck dispatch terminals. Cleaning agents include water, steam, detergents, caustic, acid, and solvents, which are applied with hand-held pressure wands or by Turco or Butterworth rotating spray nozzles. Detergent, caustic, and acid solutions are usually recycled until spent and then sent to treatment facilities; solvents are recycled in a closed system, with sludges either incinerated or landfilled. The average amount of material cleaned from each trailer is 100 kg (220 lb). Vapors from volatile materials are flared at a few terminals, but are most commonly dissipated to the atmosphere. Approximately 0.23 m^3 (60 gal) of liquid are used per tank truck steam cleaning and 20.9 m^3 (5,500 gal) for full flushing; this represents an average of 2 m^3 (500 gal) for tank truck cleaning.

4.7.1.3 Drums - Both 0.2 and 0.11 m^3 (55 and 30 gal) drums are used to ship a vast variety of commodities, with organic chemicals (including solvents) accounting for 50 percent. The remaining 50 percent include inorganic chemicals, asphaltic materials, elastomeric materials, printing inks, prints, food additives, fuel oils, and so on.

Drums made entirely of 18-gauge steel have an average life, with total cleaning, of eight trips; those with 20-gauge bodies and 18-gauge heads have an average life of three trips. Not all drums are cleaned, especially those of thinner construction.

Tight-head drums which have carried materials that are easy to clean are steamed or washed with caustic. Steam cleaning is done by inserting a nozzle into the drum, with vapors going to the atmosphere. Caustic washing is done by tumbling the drum with a charge of hot caustic solution and some pieces of chain.

Drums used to carry materials that are difficult to clean are burned out either in a furnace or in the open; those with tight-heads have the tops cut out and are reconditioned as open-head drums. Drum burning furnaces may be batch or continuous. Several gas burners completely bathe the drum in flame, burning away the contents, lining, and outside paint within a nominal 4-minute period at a temperature of at least 480° but not more than 540°C (900°F-1000°F) in order to prevent warping of the drum. Emissions are vented to an afterburner or secondary combustion chamber, where the gases are raised to at least 760°C (1,500°F) for a minimum of 0.5 second. The average amount of material removed from each drum is 2 kg (4.4 lb).

4.7.2 Emissions and Controls

4.7.2.1 Rail Tank Cars and Tank Trucks - Atmospheric emissions from tank car and truck cleaning are predominantly volatile organic chemical vapors. In order to achieve a practical but representative picture of these emissions, the organic chemicals hauled by the carriers must be broken down into classes characterized by high, medium, and low viscosities and by high, medium, and low vapor pressures. This is because high viscosity materials do not drain readily, thus affecting the quantity of material remaining in the tank, while high vapor pressure materials volatilize more readily during cleaning and tend to lead to higher emissions.

Practical and economically feasible control of atmospheric emissions from tank car and truck cleaning does not exist except for containers transporting commodities that produce combustible gases and water-soluble vapors (such as ammonia and chlorine). Gases which are displaced as tanks are filled are sent to a flare and burned. Water soluble vapors are absorbed in water and sent to the wastewater system. All other emissions are vented to the atmosphere.

Tables 4.7-1 and 4.7-2 give emission factors for representative organic chemicals hauled by tank cars and trucks, respectively.

Table 4.7-1. EMISSION FACTORS FOR RAIL TANK CAR CLEANING[1]
EMISSION FACTOR RATING: D

Compound	Chemical Class		Total Emissions[a] (g/car)
	Vapor Pressure	Viscosity	
Ethylene glycol	low	high	0.32
Chlorobenzene	medium	medium	15.7
o-Dichlorobenzene	low	medium	75.4
Creosote	low	high	2,350

[a] Total emissions = (emission rate) x (emission volume)

Table 4.7-2. EMISSION FACTORS FOR TANK TRUCK CLEANING[1]
EMISSION FACTOR RATING: D

Compound	Chemical Class		Total Emissions[a] (g/truck)
	Vapor Pressure	Viscosity	
Acetone	high	low	311
Perchloroethylene	high	low	215
Methyl methacrylate	medium	medium	32.4
Phenol	low	low	5.5
Propylene glycol	low	high	1.07

a Total emissions = (emission rate) x (emission volume)

4.7.2.2 Drums - There is no control for emissions from steaming of drums. Solution or caustic washing yields negligible air emissions because the drum is closed during the wash cycle. Atmospheric emissions from steaming or washing drums are predominantly organic chemical vapors.

Air emissions from drum turning furnaces are controlled by proper operation of the afterburner or secondary combustion chamber, where gases are raised to at least 760°C (1,500°F) for a minimum of 0.5 second. This normally ensures complete combustion of organic materials and prevents the formation, and subsequent release, of large quantities of NO_x, CO, and particulates. In open burning, however, there is no feasible way of controlling the release of incompletely burned combustion products to the atmosphere. Converting open cleaning operations to closed-cycle cleaning and eliminating open air drum burning seem to be the only control alternatives for the immediate future.

Table 4.7-3 gives emission factors for representative criteria pollutants emitted from drum cleaning.

Table 4.7-3. EMISSION FACTORS FOR DRUM BURNING[1]
EMISSION FACTOR RATING: E

Criteria Pollutant	Total Emissions[a] Uncontrolled (g/drum)	Total Emissions[a] Controlled (g/drum)
Particulates	16	12[b]
NO_x	0.89	0.018
Volatile organics	negligible	negligible

[a] Total emissions = (emission rate) x (emission volume)

[b] Derived from Reference 1, Table 17 and Appendix A

Reference for Section 4.7

1. Earley, D.R., K.M. Tackett, and T.R. Blackwood, Source Assessment: Rail Tank Car, Tank Truck, and Drum Cleaning - State of the Art. EPA-600/2-78-004g. Prepared by Monsanto Research Corporation, Dayton, Ohio 45407, for USEPA, Industrial Environmental Research Laboratory, Office of Research and Development, Cincinnati, Ohio 45268, under Contract No. 68-02-1874, April 1978

BACKGROUND DOCUMENT

SECTION 4.7 TANK AND DRUM CLEANING

1.0 INTRODUCTION

The only document readily available for use in writing AP-42 Section 4.7, "Tank and Drum Cleaning," was Monsanto Research Corporation's Source Assessment: Rail Tank Car, Tank Truck, and Drum Cleaning - State of the Art (Reference 1).

2.0 TANK CAR AND TRUCK CLEANING EMISSIONS

Tables 4.7-1 and -2 of Section 4.7 are adapted from Table 12 of Reference 1. The only explanation of the origin of the emission measurements from tank car and truck cleaning that appear in this table consists of the following text (Reference 1, p. 21):

> In order to achieve a practical, but representative, picture of these emissions, the organic chemicals hauled by the carriers were broken down into classes by high, medium, and low vapor pressures. Viscosity affects the quantity of material remaining in the tank; low viscosity materials drain readily while high viscosity materials do not. Vapor pressure affects the air emissions since high vapor-pressure materials volatize more readily during cleaning and tend to lead to higher emission rates.
>
> After the classes of chemicals had been established, the selection of the particular chemical to be sampled for was dictated by the specific materials which were being cleaned during the sampling visits.

There is no data supporting the emission factors for rail tank car cleaning (Table 4.7-1) or tank truck cleaning (Table 4.7-2) reported in Reference 1. Since the solvents carried in either rail cars or trucks are extremely variable, the emissions vary by orders of magnitude. The few individual solvents reported are only roughly representative for broad classes; moreover, the trends are in opposite directions in the two tables. Therefore the rating of D was applied to all emission factors in the two tables.

3.0 DRUM BURNING EMISSIONS

3.1 PARTICULATES

In Table 4.7-3, the controlled emission factor for particulates from drum burning was derived by dividing the total emissions for each state listed in Table 17 of Reference 1 (in metric tons per year) by the number of barrels burned annually in that state. In each case, a factor of approximately 12 grams per drum was obtained. This agrees with the factor obtained by dividing total emissions nationwide (119.6 metric tons per year) by total barrels burned (10.1 million).

The emission factor of 12 grams of particulate per drum burned is also calculated in Appendix A of Reference 1. This appendix states that the particulate emission factor for auto incineration with an afterburner is 0.68 kilograms per car, based on 113 kilograms (250 lb) of combustible material (CM) on a stripped car body (refer to AP-42, p. 2.2-1). Assuming 2 kilograms of combustible material per drum (refer to AP-40, p. 508) gives:

$$\begin{aligned} E_p &= \frac{0.68\text{ kg}}{\text{car}} \cdot \frac{\text{car}}{113\text{ kg/CM}} \cdot \frac{2\text{ kg CM}}{\text{drum}} \\ &= 0.012\text{ kg/drum} \\ &= 12\text{ g/drum} \end{aligned}$$

Performing this calculation using the particulate emission factor for uncontrolled auto incineration, namely 0.9 kilograms per car (refer to AP-42, p. 2.2-1), yields an uncontrolled emission factor of 16 grams of particulate per drum burned.

3.2 NITROGEN OXIDES

Employing the nitrogen oxides emission factors for auto incineration with an afterburner of 0.01 kilograms per car (refer to AP-42, p. 2.2-1), Appendix A of Reference 1 gives the following factor for NO_x emissions from drum burning:

$$E_{NO_x} = \frac{0.01\ \text{kg}}{\text{car}} \cdot \frac{\text{car}}{113\ \text{kg CM}} \cdot \frac{2\ \text{kg CM}}{\text{drum}}$$

$$= 1.8 \times 10^{-4}\ \text{kg/drum}$$

$$= 0.018\ \text{g/drum}$$

Use of the NO_x emission factor for uncontrolled auto incineration of 0.05 kilograms per car (refer to AP-42, p. 2.2-1) yields a factor of 0.89 grams NO_x emitted per drum burned.

3.3 EMISSION FACTOR RATING

The emission factors for particulates and NO_x for drum burning in Table 4.7-3 are based solely on an analogy to auto incineration (refer to Appendix A of Reference 1). The state particulate burning emissions data in Table 17 of that reference are apparently computed from the factor derived from auto incineration, since they are all the same, within round-off errors. The auto incineration data has a rating of B. The analogy is poor, however, because auto combustibles are largely fabric and plastics, whereas drum residues are liquid or semi-solid, for the most part. Since there are no direct data whatever for drum burning emissions, a rating of E was assigned to the emission factors in Table 4.7-3.

8.1 ASPHALTIC CONCRETE PLANTS

8.1.1 Process Description

Asphaltic concrete (asphaltic hot-mix) is a paving material which consists of a combination of graded aggregate that is dried, heated, and evenly coated with hot asphalt cement.

Asphalt hot-mix is produced by mixing hot, dry aggregate with hot liquid asphalt cement in batch or continuous processes. In the dryer drum process, another method of hot-mix asphalt production, wet aggregate is dried and mixed with hot liquid asphalt cement simultaneously in the dryer. Since different applications require different aggregate size distributions, the aggregate is segregated by size and proportioned into the mix as required. In 1975, about 90 percent of the total U.S. production was conventional batch process and most the the remainder was conventional continuous. The dryer drum process comprised less than 3 percent of the total, but most new construction favors this design. Plants may be either permanent or portable.

8.1.1.1 Conventional Plants - Conventional plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.2-2) aggregate mixing operations. The raw aggregate is normally stock-piled near the plant at a location where the moisture content will stabilize between 3 and 5 percent by weight.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas- or oil-fired rotary dryer. Because a substantial portion of the heat is

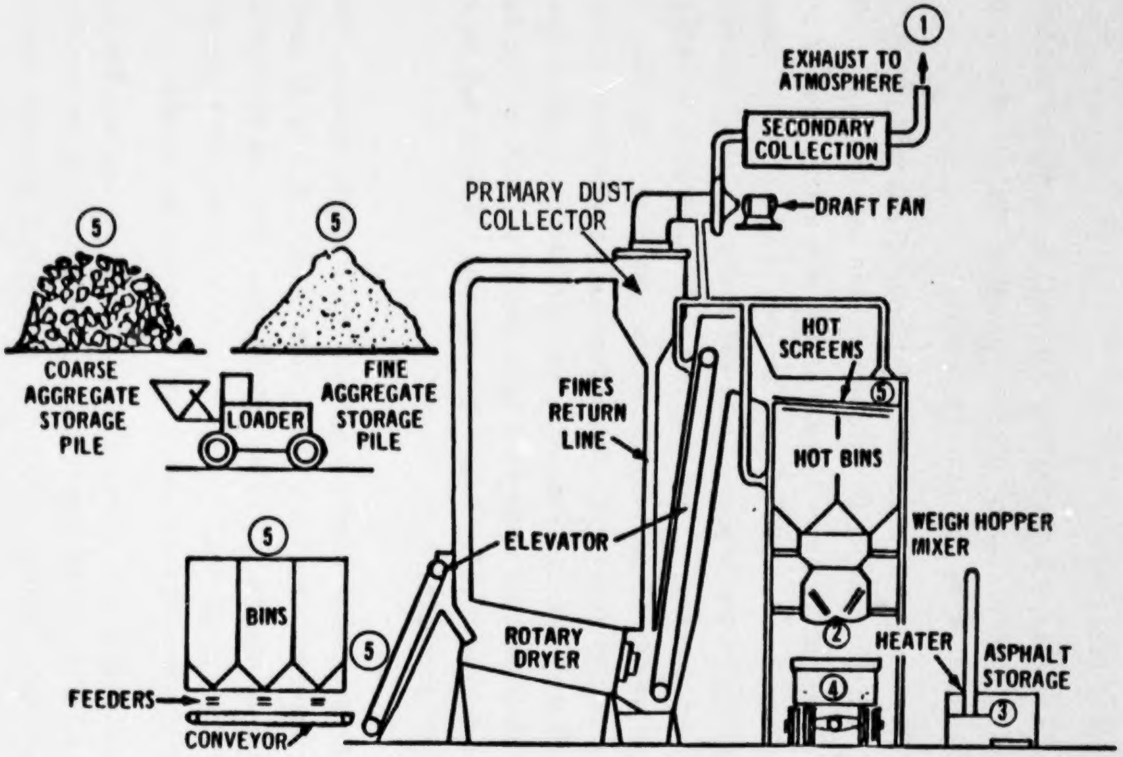

①
EXHAUST TO ATMOSPHERE
SECONDARY COLLECTION
PRIMARY DUST COLLECTOR
DRAFT FAN
⑤
⑤
COARSE AGGREGATE STORAGE PILE
LOADER
FINE AGGREGATE STORAGE PILE
FINES RETURN LINE
HOT SCREENS
⑤
HOT BINS
⑤
BINS
ELEVATOR
WEIGH HOPPER
MIXER
⑤
ROTARY DRYER
②
HEATER
ASPHALT STORAGE
④
③
FEEDERS
CONVEYOR

Figure 8.1-1. Batch Hot-Mix Asphalt Plant[a]

[a] Numbered locations are points of emission for substances listed in Table 8.1-1.

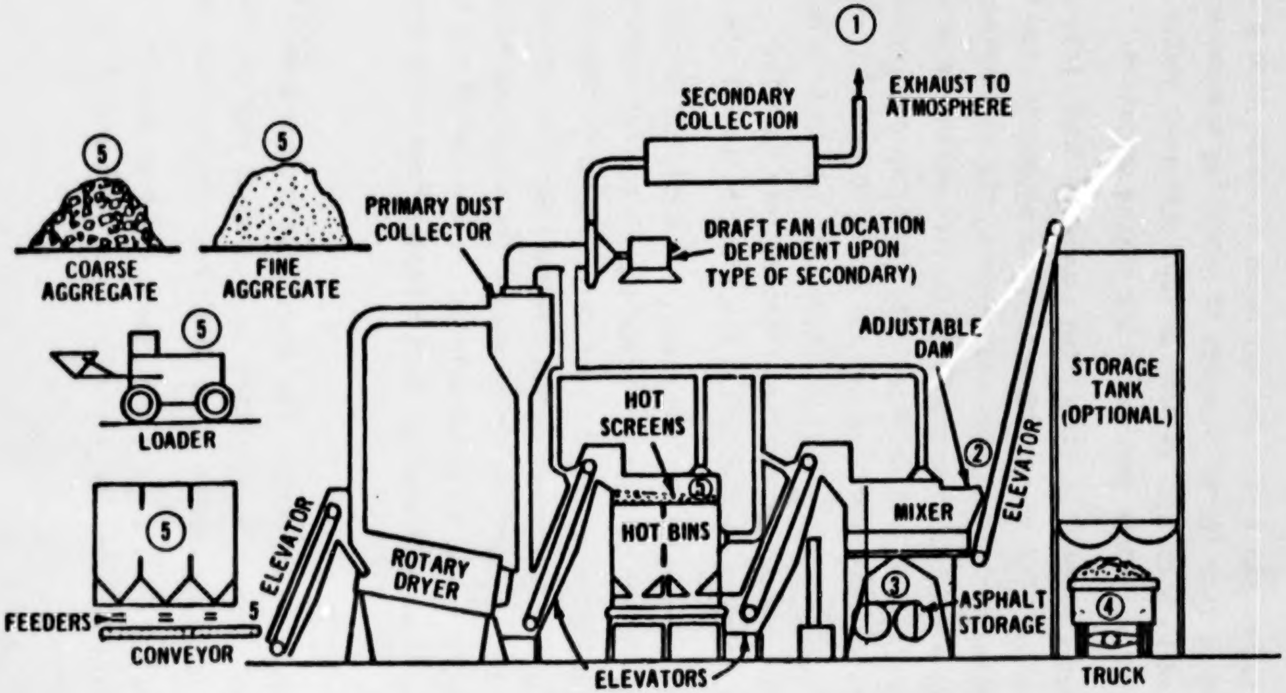

①
EXHAUST TO ATMOSPHERE
SECONDARY COLLECTION
⑤
COARSE AGGREGATE
⑤
FINE AGGREGATE
PRIMARY DUST COLLECTOR
DRAFT FAN (LOCATION DEPENDENT UPON TYPE OF SECONDARY)
⑤
LOADER
ADJUSTABLE DAM
STORAGE TANK (OPTIONAL)
HOT SCREENS
⑤
HOT BINS
②
ELEVATOR
MIXER
⑤
ELEVATOR
ROTARY DRYER
③
ASPHALT STORAGE
④
FEEDERS
5
CONVEYOR
ELEVATORS
TRUCK

Figure 8.1-2. Continuous Hot-Mix Asphalt Plant[a]

[a] Numbered locations are points of emission for substances listed in Table 8.1-1.

transferred by radiation, dryers are equipped with flights that are designed to tumble the aggregate and promote drying.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. The classified hot materials then enter the mixing operation.

In a batch plant, the classified aggregate drops into one of four large bins. The operator controls the aggregate size distribution by opening individual bins and allowing the classified aggregate to drop into a weigh hopper until the desired weight is obtained. After all the material is weighted out, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighted, and then injected into the mixer. The hot-mixed batch is then dropped into a truck and hauled to the job site.

In a continuous plant, the classified aggregate drops into a set of small bins which collect and meter the classified aggregate to the mixer. From the hot bins, the aggregate is metered through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered into the inlet end of the mixer and retention time is controlled by an adjustable dam at the end of the mixer. The mix flows out of the mixer into a hopper from which the trucks are loaded.

8.1.1.2 Dryer Drum Plants - The dryer drum process simplifies the conventional process by replacing hot aggregate storage bins, vibrating screens, and the mixer with proportioning feed controls.

Figure 8.1-3 is a diagram of the dryer drum process. Both aggregate and asphalt are introduced near the flame end of the

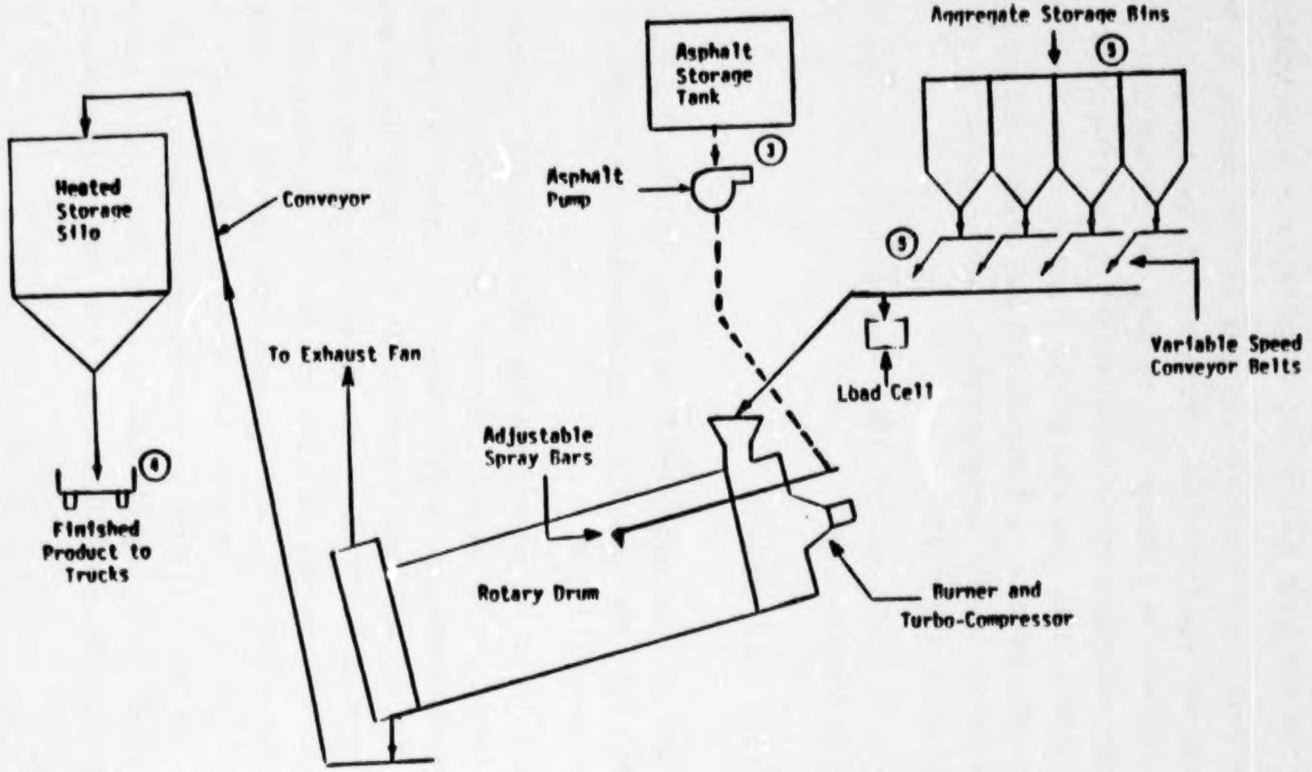

Aggregate Storage Bins
⑤
⑤
Asphalt Storage Tank
③
Asphalt Pump
Heated Storage Silo
Conveyor
To Exhaust Fan
Load Cell
Variable Speed Conveyor Belts
Adjustable Spray Bars
Rotary Drum
Burner and Turbo-Compressor
④
Finished Product to Trucks

Figure 8.1-3. Dryer Drum Hot-Mix Asphalt Plant[a]

[a] From Reference 20. Numbered locations are points of emission for substances listed in Table 8.1-1.

revolving drum. A variable-flow asphalt pump is electronically linked to the aggregate belt scales to control mix specifications.

Dryer drum plants generally use parallel flow design for hot burner gases and aggregate flow. Parallel flow has the advantage of giving the mixture a longer time to coat and collect dust in the mix, thereby reducing particulate emissions to the atmosphere. The amount of particulates generated within the dryer in this process is lower than that generated within conventional dryers, but because asphalt is heated to high temperatures for a long period of time, organic emissions are greater.

The mix is discharged from the revolving dryer drum into surge bins or storage silos.

8.1.2 Emissions and Controls

8.1.2.1 Emission Locations - Emission points at batch, continuous, and drum dryer hot-mix asphalt plants are numbered in Figures 8.1-1, -2, and -3, respectively.

Emissions from the various sources in an asphaltic concrete plant are vented either through the dryer vent or the scavenger vent. The dryer vent stream goes to the primary collector. The outputs of the primary collector and the scavenger vent go to the secondary collector, then to the stack (1) for release to the atmosphere. The scavenger vent carries releases from the hot aggregate elevator (5), vibrating screens (5), hot aggregate storage bins (5), weigh hopper, and mixer (2). The dryer vent carries emissions only from the dryer. In the dryer drum process the screens, weigh hopper, and mixer are not in a separate tower. Dryer emissions in conventional plants contain mineral fines and fuel combustion products, while the mixer assembly (2) also emits materials from the hot asphalt. In dryer drum plants, both types of emissions arise in the drum. These numbers refer to Figures 8.1-1 to 8.1-3.

Potential fugitive particulate emission sources from asphaltic concrete plants include unloading of aggregate to aggregate storage bins (5), conveying aggregate by elevators (5), and aggregate screening operations (5). Another source of particulate emissions is the mixer (2) which, although it is generally vented into the secondary collector, is open to the atmosphere when a batch is loaded onto a truck. This is an intermittent operation and the conditions of air movement are quite variable, so these emissions are best regarded as fugitive. The open truck (4) can also be a source of fugitive VOC emissions, as can the asphalt storage tanks (3), which may emit small amounts of polycyclics as well. These numbers refer to Figures 8.1-1 to 8.1-3.

Thus fugitive particulate emissions from hot-mix asphalt plants consist basically of dust from aggregate storage, handling, and transfer. Stone dust may range from 0.1 μm to more than 300 μm in diameter. On the average, 5 percent of cold aggregate feed is <4 μm (minus 200 mesh). Dust that may escape before reaching primary dust collection generally is 50 to 70 percent <4 μm (minus 200 mesh). Materials emitted are given in Tables 8.1-1 and 8.1-4.

8.1.2.2 Emission Factors - Emission factors for various materials emitted from the stack are given in Table 8.1-1. With the exception of aldehydes, the materials listed in this table are also emitted from the mixer, but mixer concentrations are 5- to 100-fold smaller than stack concentrations and last only during the discharge of the mixer. Reference 16 reports mixer concentrations of SO_x, NO_x, VOC, and ozone as less than certain values, so they may not be present at

Table 8.1-1. EMISSION FACTORS FOR SELECTED MATERIALS FROM AN ASPHALTIC CONCRETE PLANT STACK[16]

Material Emitted[a]	Emission Factor Rating	Emission Factor[b]	
		g/MT	lb/ton
Particulate[c]	B	137	.274
Sulfur oxides (as SO_2)[c,d]	C	146S	.292S
Nitrogen oxides (as NO_2)[e]	D	18	.036
Volatile organic compounds (expressed as methane equivalents)[e]	D	14	.028
Carbon monoxide[e]	D	19	.038
Polycyclic organic material[e]	D	0.013	.000026
Aldehydes[e]	D	10	.020
Formaldehyde	D	0.077	.00015
2-Methylpropanal (isobutyraldehyde)	D	0.63	.0013
1-Butanal (n-butyraldehyde)	D	1.2	.0024
3-Methylbutanal (isovaleraldehyde)	D	8.3	.016

[a] Particulates, carbon monoxide, polycyclics, trace metals, and hydrogen sulfide were observed in the mixer emissions at concentrations that were small relative to stack concentrations. Refer to Section 8.1.2.2.

[b] Expressed as grams per metric ton and lb/ton of asphaltic concrete produced.

[c] Mean of 400 plant survey source test results.

[d] S = percent sulfur in fuel. SO_2 may be attenuated more than 50 percent by adsorption on alkaline aggregate (Reference 21).

[e] Based on limited test data from the single asphaltic concrete plant described in Table 8.1-2.

all, while particulates, carbon monoxide, polycyclics, track metals, and hydrogen sulfide were observed at concentrations that were small relative to stack concentrations. Emissions from the mixer are thus best treated as fugitive.

The materials listed in Table 8.1-1 are discussed below. Factor ratings are listed for each material in the table. All emission factors are for controlled operation, either based on average industry practice shown by survey, or on actual results of testing in a selected typical plant. The characteristics of this representative plant are given in Table 8.1-2.

The particulate emission factor was derived from a 400 plant sample of the U.S. hot-mix asphalt industry. The extremes for this sample range over three orders of magnitude, but 76 percent of the plants have emission rates below the mean.

The industrial survey showed that over 66 percent of operating hot-mix asphalt plants use fuel oil for combustion. Possible sulfur oxides emissions from the stack were calculated assuming that all sulfur in the fuel oil is oxidized to SO_x. (No. 2 fuel oil has an average sulfur content of 0.22 percent.) The amount of sulfur oxides actually released through the stack may be attenuated by water scrubbers or even by the aggregate itself, where limestone is being dried.

Emission factors of nitrogen oxides, nonmethane volatile organics, carbon monoxide, polycyclic organic material, and aldehydes were determined by sampling the stack gas at the representative asphalt hot-mix plant.

8.1.2.3 Emission Controls - The choice of applicable control equipment ranges from dry mechanical collectors to scrubbers and fabric

Table 8.1-2. CHARACTERISTICS OF AN ASPHALTIC CONCRETE PLANT SELECTED FOR SAMPLING[a]

Parameter	Plant Sampled
Plant type	Conventional permanent batch plant
Production rate, Metric tons/hr (tons/hr)	160.3 ± 16 percent (177 ± 16 percent)
Mixer capacity, Metric tons (tons)	3.6 (4.0)
Primary collector	Cyclone
Secondary collector	Wet scrubber (venturi)
Fuel	Oil
Release agent	Fuel oil
Stack height, m (ft)	15.85 (52)
Particulate emission rate, kg/hr (lb/hr)	7.7 ± 48 percent (17.0 ± 48 percent)

[a] From Reference 16, Table 16

collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment, such as large diameter cyclones, skimmers, or settling chambers. These chambers are often used as classifiers where the collected material is returned to the hot aggregate elevator and combined with the dryer aggregate load. The air discharge from the primary collector is seldom vented to the atmosphere because high emission levels would result. The primary collector effluent is therefore ducted to a secondary collection device.

Particulate emission factors for conventional asphaltic concrete plants are presented in Table 8.1-3. Particle size distribution information has not been included because the particle size distribution varies with the aggregate being used, the mix being made, and the type of plant operation. Potential fugitive particulate emission factors for conventional asphaltic concrete plants are shown in Table 8.1-4.

Particulate emission factors for dryer drum plants are presented in Table 8.1-5. (There are no data for other pollutants released from the dryer drum hot-mix process.) Particle size distribution has not been included because it varies with the aggregate used, the mix made, and the type of plant operation. Emission factors for particulates in an uncontrolled plant can vary by a factor of 10, depending upon the percent of fine particles in the aggregate.

Table 8.1-3. PARTICULATE EMISSION FACTORS FOR CONVENTIONAL HOT-MIX ASPHALTIC PLANTS[a]

EMISSION FACTOR RATING: B

Type of Control	Emission Factor[b]	
	kg/MT	lb/ton
Uncontrolled[c,d]	22.5	45.0
Precleaner[d]	7.5	15.0
High-efficiency cyclone	0.85	1.7
Spray tower	0.20	0.4
Baffle spray tower	0.15	0.3
Multiple centrifugal scrubber[e]	0.035	0.07 (.007-.138)
Orifice-type scrubber	0.02	0.04
Venturi scrubber[f]	0.02	0.04 (.025-.053)
Baghouse[g]	0.01	0.02 (0.07-.036)

[a] References 1, 2, 5-10, and 14-16.

[b] Factors experssed in terms of emissions per unit weight of asphalt concrete produced.

[c] Almost all plants have at least a precleaner following the rotary dryer.

[d] These factors differ from those given in Table 8.1-1 because they are for uncontrolled emissions and are from an earlier survey. Refer to Reference 16.

[e] The average emission from a properly designed, installed, operated, and maintained scrubber, based on a study to develop new source performance standards. Refer to Reference 15.

[f] References 14 and 15.

[g] Emissions from a properly designed, installed, operated, and maintained baghouse, based on a study to develop new source performance standards. Refer to References 14 and 15.

Table 8.1-4. POTENTIAL UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALTIC CONCRETE PLANTS

EMISSION FACTOR RATING: E

Type of Operation	Particulates[a]	
	kg/MT	lb/ton
Unloading coarse and fine aggregate to storage bins[b]	0.05	0.10
Cold and dried (and hot) aggregate elevator[b]	0.10	0.20
Screening hot aggregate[c]	0.013	0.026

[a] Factors expressed as units per unit weight of aggregate.

[b] Reference 18, assumed equal to similar sources.

[c] Reference 19, assumed equal to similar crushed granite processes.

Table 8.1-5 PARTICULATE EMISSION FACTORS FOR DRYER DRUM HOT-MIX ASPHALT PLANTS[11]

EMISSION FACTOR RATING: B

Type of Control	Emission Factor[a]	
	kg/MT	lb/ton
Uncontrolled	2.45	4.9
Cyclone or multicyclone	0.34	0.67
Low energy wet scrubber[b]	0.04	0.07
Venturi scrubber	0.02	0.04

[a] Factors expressed in terms of emissions per unit weight of asphalt concrete produced. These factors vary from those for conventional asphaltic concrete plants because the aggregate contacts and is coated with asphalt early in the dryer drum process.

[b] Either stack sprays where water droplets are injected into the exit stack or a dynamic scrubber that incorporates a wet fan.

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BACKGROUND DOCUMENT

SECTION 8.1 ASPHALTIC CONCRETE PLANTS

1.0 INTRODUCTION

In December 1977, AP-42 Section 8.1, "Asphaltic Concrete Plants," was revised, but still included particulate emission factors only. The explanatory information submitted at that time corresponds to Sections 4.1 and 4.3 of this background document.

In August 1978, the additions of organic emission factors and factor ratings were assigned under a separate contract and task order. The background information for these factors and factor ratings appears in Sections 2.0, 3.0 and 4.2 of this document.

The stack emission factors presented in Table 8.1-1 are based either on the mean of a 400 plant survey or on sampling data from a representative hot-mix asphalt plant with the characteristics listed in Table 8.1-2. The data, calculations, and emission factors appear in Monsanto Research Corporation's (MRC) Source Assessment: Asphalt Hot-Mix (Reference 16).

The particulate emission factors for conventional hot-mix asphalt plants given in Table 8.1-3 are derived from several sources by the methods described in Section 4.1 of this document.

The potential uncontrolled fugitive particulate emission factors for conventional plants given in Table 8.1-4 were determined from References 18 and 19, as Section 4.2 describes.

Section 4.3 presents the data from JACA Corporation's Preliminary Evaluation of Air Pollution Aspects of the Drum-Mix Process (Reference 11) that were used to calculate the particulate emission factors for drum dryer asphaltic concrete plants shown in Table 8.1-5.

2.0 EMISSION FACTORS FOR SELECTED MATERIALS FROM AN ASPHALTIC CONCRETE PLANT STACK (Tables 8.1-1 and 8.1-2)

The emission factors presented in Table 8.1-1 appear in Tables 11 and 13 of Reference 16, and are based either on the mean of a 400 plant survey or on the plant characteristics listed in Table 8.1-2, as indicated in the notes to Table 8.1-1. Table 8.1-2 corresponds to Table 16 of Reference 16 (p. 53). The emission factors were calculated as follows:

2.1 PARTICULATE

As indicated in footnote a of Table 11 (Reference 16, p. 50), the particulate emission factor of 137 grams of particulate per metric ton of asphaltic concrete produced was calculated from the mean value of 6.09 grams per second (983.20 lb/hr) in Figure 12, "Asphaltic Hot-Mix Emission Rate" (Reference 16, p. 48), and the mean average production rate of 160 metric tons of asphalt per hour (176.4 ton/hr) from Question No. 62 of Table A-1, "Summary of Asphalt Hot-Mix Industry Survey Data" (Reference 16, p. 96). Table A-1 is from MCR's Asphalt Industry Survey, conducted through the National Asphalt Pavement Association (NAPA, November 23, 1975, 24 pages):

$$E_p = \frac{983.20 \text{ lb/hr}}{176.4 \text{ ton/hr}}$$

$$= 5.57 \text{ lb/ton} \approx 137 \text{ g/MT}$$

2.2 SULFUR OXIDES

The following explanation of the calculation of the sulfur oxides emission factor of 32 grams per metric ton is from Appendix F of Reference 16, "Calculation of Emission Factors Based on MRC Sampling Data" (pp. 150-151):

- 40 percent of the asphalt industry uses No. 2 fuel oil (according to Asphalt Industry Survey, MRC, op. cit.)
- Average sulfur contents of No. 2 fuel oil = 0.22 (Chemical Engineers' Handbook, Perry and Chilton, eds., McGraw-Hill, 1973)
- An average of 2 gallons of No. 2 fuel oil is consumed to dry and heat aggregate for one ton of hot-mix ("Fuel Conservation," Foster and Kloiber, NAPA, Riverdale)
- Density of No. 2 fuel oil = 7.31 lb/gal (Chemical Engineers' Handbook, op. cit.) lb of fuel oil consumed to dry 1 ton hot-mix = 2 x 7.31 = 14.62 lb
- 100 lb of fuel oil contain S lb sulfur
  ∴14.62 lb of fuel oil contain 0.146(S) lb sulfur
- $\underset{(32)}{S} + \underset{(32)}{O_2} \rightarrow \underset{(64)}{SO_2}$
- 32 lb sulfur burn to form 64 lb SO_2
  ∴0.146 lb sulfur burns to form 64/32 x 0.146(S) lb SO_2
  = 0.292(S) lb SO_2

Therefore the emission factor is 0.292(S) lb SO_2/ton or 0.146(S) kg SO_2 per metric ton of asphalt produced.

The calculated SO_2 was based on knowledge of type of fuel used and the typical sulfur content, not on fuel analysis for sulfur. The only characterization of the aggregate was the pH, although the sources of aggregate (the site locations in Table I of Reference 21) were widespread: Iowa, Pennsylvania, Georgia, and so on. Tables I and III from Reference 21 are reproduced here as Tables 1 and 2 respectively.

2.3 NITROGEN OXIDES

Calculation of the nitrogen oxides emission factor of 18 grams per metric ton is also given in Appendix F of Reference 16 (pp. 149-150):

- Concentration of nitrogen dioxide detected in stack gas is <29 ppm by volume
- Gas flow rate through stack = 27,487 ft^3/min
- Density of nitrogen dioxide = 0.1287 lb/ft^3 (Chemical Engineers' Handbook, op. cit.)
- Production rate during sampling = 176.4 ton/hr
- 10^6 ft^3 of stack gas contain 29 ft^3 of NO_x
  ∴27,487 ft^3 of stack gas contain $29/10^6 \times 27,487$ ft^3 NO_x
  = 0.80 ft^3 NO_x
- 1 ft^3 NO_x weighs 0.1287 lb
  ∴0.80 ft^3 NO_x weighs $0.1287 \; lb/ft^3 \times 0.80 \; ft^3 = 0.10$ lb
- In 1 minute, 0.10 lb NO_x flows through the stack
  ∴In 60 minutes, 6.16 lb NO_x flow through the stack
- 176.4 tons of asphalt produced per hr emit 6.16 lb NO_x
  ∴1 ton of asphalt produced emits 0.035 lb NO_x

Therefore the emission factor is 0.035 lb NO_x/ton or 0.0176kg NO_x per metric ton of asphalt produced.

2.4 VOLATILE ORGANIC COMPOUNDS

The emission factor for volatile organic compounds (VOC) of 14 grams per metric ton of asphaltic concrete produced was calculated as follows (Reference 16, Appendix F, p. 151):

Table 1. ASPHALT INDUSTRY MONITORING RESULTS

		Dryer Capacity	Exiting Temperature	Gas Composition (percent)			SO_2 Concentration (ppm)		Dust	Excess Air
Site	Fuel	T/hr	°F	CO_2	O_2	H_2O	Measured	Calculated	pH	Percent
1	#2 Oil & Natural Gas	200	160-210	1.4	17.5	-	5	12	7.0	475
2	#2 Oil & Natural Gas	-	150-230	2.2	16.7	-	5	18	7.0	388
3	#2 Oil	100	325-395	2.1	17.9	-	20	49	11.2	548
4	#2 Oil	150	195	2.2	17.1	8.1	10	52	9.3	416
5	#2 Oil	250	260	1.6	17.0	4.2	0	100	-	404
6	#2 Oil	150	305	4.5	15.0	11.7	10-25	38	9.7	212
7	#5 Oil	150	150-185	2.1	18.5	10.5	10	171	10.8	672
8	#5 Oil	150	290-360	2.4	17.4	2.8	65-230	214	6.9	459

[a] From Reference 21, Table I.

Table 2. MONITORING OF TURBULENT MASS MIXER ASPHALT PLANT[a]

Operating Conditions	
Capacity	100 T/D
Fuel	#2 Oil
Asphalt Temperature	315°F
Injection Rate	5%
Baghouse - Type	Plenum Pulse
- Temperature	305°F
- Bags	Nomex
- Pressure Drop	4-5 in H_2O
Gas Stream[b]	
SO_2	18 ppm (calc = 38 ppm)
CO_2	4-4.5%
O_2	14-15%
H_2O	12%
Dust - pH	9.7
Hydrocarbons	
Dust	Trace
Condensate	Trace
Excess Air	212%

[a] From Reference 21, Table III

[b] Measurements made by Du Pont

- Concentration of VOC in stack gas = 42.3 ppm
- Gas flow rate through the stack = 32,350 ± 5,133 ft^3/min
- Density of hydrocarbons emitted ≃ 0.0448 lb/ft^3 (Chemical Engineers' Handbook, op. cit.)
- Production rate during sampling = 130 ton/hr
- 10^6 ft^3 of stack gas contain 42.3 ft^3 VOC
  ∴32,350 ft^3 of stack gas contain $42.3/10^6 \times 32,350$ ft^3 HC
  = 1.37 ft^3 VOC
- 1 ft^3 of VOC weighs 0.0448 lb
  ∴1.37 ft^3 VOC weighs 0.0448 $lb/ft^3 \times 1.37$ ft^3 = 0.061 lb
- In 1 minute, 0.061 lb VOC flows through the stack
  ∴In 60 minutes, 3.68 lb VOC flow through the stack
- 130 tons of asphalt produced per hr emit 3.68 lb VOC
  ∴1 ton of asphalt produced emits 0.028 lb VOC

The emission factor is thus 0.028 lb VOC/ton or 0.014 kg VOC per metric ton asphalt produced.

2.5 CARBON MONOXIDE

The carbon monoxide emission factor given in Table 8.1-1 is 19 grams per metric ton. Reference 16, Appendix F, p. 149 gives the following account of how this factor was calculated:

- Concentration of carbon monoxide in stack gas = 32.2 ppm
  17.6 percent by volume
- Gas flow rate through stack = 32,350 ft^3/min
- Density of carbon monoxide = 0.0781 lb/ft^3 (Chemical Engineers' Handbook, op. cit.)
- Production rate during sampling = 130 ton/hr
- 10^6 ft^3 of stack gas contain 32.2 ft^3 of CO
  ∴32,350 ft^3 of stack gas contain $32.2/10^6 \times 32,350$ ft^3 CO
  = 1.04 ft^3 CO

- ● 1 ft^3 CO_2 weighs 0.0781 lb
  ∴1.04 ft^3 CO weighs 0.0781 lb/ft^3 x 1.04 ft^3 = 0.081 lb
- ● In 1 minute, the CO flowing through the stack is 0.081 lb
  ∴In 60 minutes, the CO flowing through the stack is 4.87 lb
- ● 130 tons of asphalt produced per hr emit 4.807 lb CO
  ∴1 ton of asphalt produced per hr emits 0.0375 lb CO

The emission factor is thus 0.0375 lb CO/ton or 0.0188 kg CO per metric ton asphalt produced.

2.6 POLYCYCLIC ORGANIC MATERIAL

The emission factor for polycyclic organic material (POM) shown in Table 8.1-1 is 0.013 grams per metric ton. Footnote c of Table 11 of Reference 16 indicates that the calculation of this emission factor is shown in Table B-20 of Appendix B, "Results from Representative Plant Sampled by MRC" (p. 112). Table B-20 is reproduced here as Table 3:

Table 3. OUTLET POM EMISSION RATE

Run No.	Emission rate, kg/hr (lb/hr)	Production rate, metric tons/hr (tons/hr)	Emission factor[a] kg/metric ton (lb/ton)
1[b]	0.0027 (0.006)	57.0 (62.8)	4.8×10^{-5} (9.6×10^{-5})
2	0.0014 (0.003)	119.3 (131.5)	1.2×10^{-5} (2.3×10^{-5})
3	0.0018 (0.004)	133.1 (146.7)	1.4×10^{-5} (2.8×10^{-5})

[a] Mean emission factor = 1.25×10^{-5} ± 38.2% kg/metric ton (2.5×10^{-5} ± 38.2% lb/ton)

[b] Not included during averaging because of difficulties during sampling.

2.7 ALDEHYDES

2.7.1 GENERAL EMISSION FACTOR

The overall emission factor for aldehydes is 10 grams per metric ton. Appendix F of Reference 16 (p. 152) gives the following explanation of how this factor was calculated:

- Concentration of aldedehydes in stack gas = 14.8 ppm 33 percent
- Gas flow rate through stack = 32,350 ft^3/min
- Density of acetaldehyde = 0.1235 lb/ft^3 (*Chemical Engineers' Handbook*, op. cit.)
- Production rate during sampling = 130 tons/hr
- 10^6 ft^3 of stack gas contain 14.8 ft^3 aldehydes
  ∴32,350 ft^3 stack gas contain 14.8/10^6 x 32,350 ft^3 aldehydes = 0.48 ft^3 aldehydes
- 1 ft^3 aldehyde weighs 0.1235 lb
  ∴0.48 ft^3 aldehyde weighs 0.059 lb
- In 1 minute, 0.059 lb aldehyde flow through the stack
  ∴In 60 minutes, 3.55 lb aldehyde flow through the stack
- 176.4 tons of asphalt produced per hr emit 3.55 lb aldehyde
  ∴1 ton of asphalt produced emits 0.020 lb aldehyde

Thus the emission factor is 0.020 lb aldehydes/ton or 0.0101 kg aldehydes/metric ton asphalt produced.

2.7.2 SPECIES EMISSION FACTORS

The emission factors for the four species of aldehydes given in Table 8.1-1 are shown in Table 13 of Reference 16 (p. 51). Footnote a of Table 13 indicates that these factors were calculated from the production rate and emission rate shown in Table B-33 of

Reference 16 (p. 113), which is reproduced below as Table 4. (However, the terms "isobutanol" and "isopentanol" are neither systematic nor common names, but hybrids not customarily used.)

Table 4. ALDEHYDES DETECTED IN SAMPLES COLLECTED AT OUTLET

Run No.	Aldehyde	Concentration		Emission Rate		
		g/ml	g/m^3	g/hr	Mean mg/s	
1	Formaldehyde	0.2	215	12.3		
2	Formaldehyde	0.11	187	10.7	3.4	26%
3	Formaldehyde	0.2	247	14.2		
1	Isobutanal	3	3,213	184		
2	Isobutanal	<0.2	<339	19.4	28	350%
3	Isobutanal	30	37,076	2,130[a]		
1	Butanal	3	3,213	184.2		
2	Butanal	2	<3,390	194.3	53	12%
3	Butanal	7	8,828	506[a]		
1	Isopentanal	20	21,540	1,230		
2	Isopentanal	<<0.1	<<177	10.1[a]	370	30%
3	Isopentanal	20	24,718	1,420		

[a] Not averaged

No further explanation of the method used to calculate these emission factors appears in Appendix B or elsewhere in Reference 16. The values for replicate analyses given in Table 4 (Table B-23 of Reference 16) show poor repeatability and, as footnote a indicates, some were not averaged with the rest (although no reason for these omissions is given).

3.0 EMISSION FACTOR RATINGS

The factor ratings assigned to each emission factor listed in Table 8.1-1 were arrived at by applying PES' best engineering judgment to the source test information upon which each calculation was based.

The particulate emission factor was rated "B" because it is based on data on emissions and operating parameters for a large sample of the asphalt hot-mix industry, covering a broad spectrum of plant types and conditions.

The sulfur oxides emission factor is also based on emissions and operating data for a large sample of the asphaltic concrete industry, but was assigned a rating of "C" because of the variable reduction in the SO_2, dependent on the nature of the aggregate (refer to Section 2.2 and Reference 21).

The nitrogen oxides, VOC, carbon monoxide, POM, and aldehydes emission factors were rated "D" because they are based on limited source test data from the single asphaltic concrete plant described in Table 8.1-2 (Table 16, p. 53, of Reference 16).

4.0 PARTICULATE EMISSION FACTORS

4.1 CONVENTIONAL ASPHALTIC CONCRETE PLANTS (Table 8.1-3)

Source test information from EPA's Background Information for New Source Performance Standards (APTD-1352B and APTD-1352C, References 14 and 15) was used to update existing AP-42 particulate emission factors for conventional asphaltic concrete plants shown in Table 8.1-3. Sections 4.1.1 to 4.1.3 give background information for the factors which were modified or added.

4.1.1 PARTICULATE EMISSION FACTORS FOR PLANTS EQUIPPED WITH "MULTIPLE CENTRIFUGAL SCRUBBER"

Source test results, which are presented in Table 5, were taken from Appendix A of Reference 15. In this report, the term "multiple centrifugal scrubber" applies to various combinations of cyclones, low energy wet scrubbers, and wet fans in series. In the study, a total of 17 source tests were conducted on nine plants equipped with properly designed, operated, and maintained scrubbers. Data for plants equipped with multiple centrifugal scrubbers were collected using the San Bernardino County Air Pollution District's test procedure. The average emission factor from these plants was derived by simple averaging of the source test results, as follows:

$$E_f = \frac{\sum_{i=1} E_{if}}{17} = 0.0743 \approx 0.07 \text{ lb/ton} \quad (2)$$

where

E_f = average emission factor
E_{if} = emission factor derived from individual source test
i = source test number (from 1 to 17)

The range shown in parentheses in Table 8.1-3 is taken from Table 5.

Table 5. PARTICULATE EMISSION FACTORS FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS EQUIPPED WITH MULTIPLE CENTRIFUGAL SCRUBBER AS CONTROL DEVICE

Code of Facility	Emission Factor (lb/ton)			Collector	Reference Page[a]
	Test 1	Test 2	Test 3		
X	0.081	0.0975		TC[b]	67
Y	0.007			TC	68
Z	0.116			TC	69
AA	0.014	0.004		TC	70
BB	0.0293	0.0408		PF[c]	71
CC	0.059			TC	72
DD	0.057	0.056	0.094	PF	73
EE	0.103	0.123	0.138	PF	74
FF	0.124	0.120		PF	75

[a] Page number for report APTD-1352C, Vol. 3 (Reference 15)
[b] Total catch
[c] Probe and filter catch

4.1.2 PARTICULATE EMISSION FACTORS FOR PLANTS EQUIPPED WITH VENTURI SCRUBBER

Source test results, which are presented in Table 6, were taken from the New Source Performance Standards publications APTD-1352B and APTD-1352C (References 14 and 15). In these studies, a total of four source tests were conducted on four plants equipped with venturi scrubbers. The data for plants equipped with venturi scrubbers were gathered using test procedures in general conformance with EPA Method 5. The emission factor from a plant equipped with a venturi scrubber was estimated by averaging the results from all of the above source tests, as follows:

$$E_f = \frac{\sum_{i=1}^{4} E_{if}}{4} = 0.039 \approx 0.04 \text{ lb/ton} \qquad (3)$$

where

E_f = average emission factor

E_{if} = emission factor derived from individual source test

i = source test number from 1 to 4)

The range shown in Table 8.1-3 is taken from the results given in Table 6.

Table 6. PARTICULATE EMISSION FACTORS FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS EQUIPPED WITH VENTURI SCRUBBER AS CONTROL DEVICE

Code of Facility	Emission Factor (lb/ton)	Collector	Reference Page
C	0.037	PF[a]	10[c]
H_1	0.044	PF	15[c]
H_2	0.025	TC[b]	16[c]
U	0.053	PF	64[d]

[a] Probe and filter catch
[b] Total catch
[c] Page number for report APTD-1352B, Vol. 2 (Reference 14)
[d] Page number for report APTD-1352C, Vol. 3 (Reference 15)

4.1.3 PARTICULATE EMISSION FACTOR FOR PLANTS EQUIPPED WITH BAGHOUSES

Source test results, which are presented in Table 7, were taken from the New Source Performance Standards publications

APTD-1352B and APTD-1352C (References 14 and 15). In these studies, a total of six source tests were conducted on six plants equipped with baghouses. The data for plants equipped with baghouses were collected using test procedure in general conformance with EPA Method 5. The emission factor from a plant equipped with a baghouse was derived by averaging the results from the above source tests, as follows:

Table 7. PARTICULATE EMISSION FACTORS FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS EQUIPPED WITH BAGHOUSE AS CONTROL DEVICE

Code of Facility	Emission Factor (lb/ton)	Collector	Reference Page
A_1	0.016	PF[a]	7[b]
A_2	0.0243	PF	8[b]
B	0.007	PF	9[b]
D	0.016	PF	11[b]
L	0.0087	PF	20[b]
O	0.036	PF	58[c]

[a] Probe and filter catch
[b] Page number for report APTD-1352B, Vol. 2 (Reference 14)
[c] Page number for report APTD-1352C, Vol. 3 (Reference 15)

$$E_f = \frac{\sum_{i=1}^{6} E_{if}}{6} = 0.018 \approx 0.02 \text{ lb/ton} \qquad (4)$$

where

E_f = average emission factor

E_{if} = emission factor derived from individual source test

i = source test number (from 1 to 6)

The range given in Table 8.1-3 is taken from Table 7.

4.1.4 EMISSION FACTOR RATING

The emission factors presented in Table 8.1-3 were rated "B" because of the quality of the emission test data, the number of separate plants tested, and the adequacy of process and engineering information.

4.2 FUGITIVE PARTICULATE FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS (Table 8.1-4)

References 18 and 19 were the primary sources of the potential fugitive particulate emision factors given in Table 8.1-4. The following EPA document was written using these two references and may be substituted as the source of this information:

> Zoller, J., T. Bertke, and T. Janszen. Assessment of Fugitive Particulate Emission Factors for Industrial Processes. EPA-450/3-78-107. PEDCo Environmental, Cincinnati, Ohio. Prepared for U.S. Environmental Protection Agency, OAQPS, Research Triangle Park, N.C., September 1978.

An uncontrolled fugitive particulate factor of negligible to .05 kg/Mg (0.1 lb/ton) of aggregate handled has been determined (Monsanto Research and Environmental Research Technology) for losses from unloading coarse/fine aggregate to storage bins, and a factor of negligible to 0.1 kg/Mg (0.2 lb/ton) has been determined for elevator conveying of cold and dried (hot) aggregate. These determinations are based on similar processing at granite quarries and coal mining operations (Reference 18). An uncontrolled fugitive emission rate ranging from negligible to 0.013 kg/Mg (0.026 lb/ton) of aggregate handled has been determined for the screening of hot aggregate, based on Monsanto Research Corporation test values for crushed granite processing (Reference 19). Extensive particulate fugitive emission test sampling data from asphaltic concrete batching plants are needed to obtain representative data for documentation in AP-42. For this reason, these factors have been assigned a reliability rating of E.

4.3 DRYER DRUM HOT ASPHALT PLANTS (Table 8.1-5)

4.3.1 EMISSION FACTORS

Source test information from Preliminary Evaluation of Air Pollution Aspects of the Drum-Mix Process (Reference 11) was the only data used to derive the emission factors presented in Table 8.1-5. In this study, particulate emission concentrations were obtained from field test data gathered at different plants with different control devices. The results are summarized in Table 8, which presents the average particulate concentrations in the stacks of dryer drum plants with different control devices.

Particulate concentrations in the stacks were obtained from 70 different plant tests. Thirty-one additional test runs that were from plants where only the aggregate data were made available by the manufacturer were not included. In deriving the emission factors, seven test results from the 70 reported were excluded for the following reasons: two tests were run outside the isokinetic range;

Table 8. PARTICULATE EMISSION CONCENTRATIONS FROM A PARALLEL-FLOW DRYER DRUM HOT-MIX ASPHALT PLANT

Number of Plants Tested	Control Device	Particulate Concentration (grain/dscf)	Reference Page[a]
9[b]	Uncontrolled	6.19	32
7	Dry mechanical collector	0.853	34
24	Wet scrubber	0.094	35
18	Venturi scrubber	0.0557	37

[a] Page number in EPA-340/1-77-004 (Reference 1)

[b] An additional 5 plants had much lower average reading and were not included

three tests were performed on nonrepresentative drum dryer plants; and two tests were duplicates.

Of the 63 tests that were acceptable for inclusion in the analysis, 14 were on uncontrolled plants; seven were on plants with dry mechanical controls, such as cyclones and multicyclones; 24 were from plants with scrubbers of the spray impingement or wet fan type; and 18 were on plants with venturi scrubbers of varying pressure drops.

The 63 tests gave a total of 158 independent runs for analysis, of which 108 reported only "front-half" results, seven reported only the "total" particulate matter, and 43 reported both front-half as well as total particulate concentration.

The average emission concentrations obtained from the above source tests for each degree of control are reported in Table 8. Emission concentrations multiplied by the average stack gas flow

1' -

per ton of product yield the emission factors shown in Table 9. The typical range of stack flow gas from a dryer drum plant is between 4,000 and 7,000 dscf/ton, depending on burning conditions. The average stack gas flow used was 5,500 dscf/ton.

Table 9. PARTICULATE EMISSION FACTORS FROM A PARALLEL-FLOW DRYER DRUM HOT-MIX ASPHALT PLANT

	Emission Factor[a]	
Degree of Control	lb/ton	kg/MT
Uncontrolled	4.9	2.45
Cyclone or multi-cyclone	0.67	0.34
Wet scrubber[b]	0.07	0.04
Venturi scrubber	0.04	0.02

[a] Emission factors expressed as units per unit weight of asphalt concrete produced

[b] Wet scrubbers include stack spray, wet fan, and dynamic scrubber

Particulate emission factors were obtained by using the following relation:

$$\text{Particulate emission factor} = \text{Particulate emission concentration} \times 5{,}500 \qquad (5)$$

$$\text{Uncontrolled emission emission} = 6.19\ \frac{\text{grain}}{\text{dscf}} \times \frac{1}{7{,}000} \times \frac{\text{lb}}{\text{grain}} \times \frac{5{,}500\ \text{dscf}}{1\ \text{ton}}$$

$$= 4.86 \approx 4.9\ \text{lb/ton}$$

$$\text{Cyclone or multicyclone} = 0.853 \times \frac{1}{7{,}000} \times 5{,}500 = 0.67\ \text{lb/ton}$$

$$\text{Wet scrubber} = 0.094 \times \frac{1}{7{,}000} \times 5{,}500 = 0.074 \approx 0.07\ \text{lb/ton}$$

$$\text{Venturi scrubber} = 0.0557 \times \frac{1}{7{,}000} \times 5{,}500 = 0.044 \approx 0.04\ \text{lb/ton}$$

4.3.2 EMISSION FACTOR RATING

The rating for the particulate emission factors presented in Table 8.1-5 was designated "B" due to the amount and reliability of the available source test data.